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FOG AND HAZE, THEIR CAUSES, DISTRIBUTION, AND FORECASTING

(A report prepared for the Daniel Guggenheim Fund for the Promotion of Aeronautics)

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[U. S. Weather Bureau, Washington, D. C., October, 1928]

SYNOPSIS

This paper contains the results of a year's study of fog and haze, both their present synoptic treatment and the more recent literature dealing with them at some of the principal European forecast and aviation centers. The greater part of the investigation was made at the Geophysical Institute of Bergen, Norway, with shorter stays at Lindenburg Aeronautical Observatory and Tempelhof Field near Berlin, at the meteorological office and Le Bourget, Paris, and at the meteorological office and Croyden, London.

Grateful acknowledgments are due to the officials of and others connected with those institutions for courtesies shown during this investigation.

Part I contains a brief summary of the present state of our knowledge of nuclei of condensation, paying special attention to Aitken's and Köhler's investigations of hygroscopic nuclei, and the general evidence favoring the theory that condensation begins on hygroscopic nuclei rather than on ions or neutral dust particles.

Part II contains a general classification of the kinds of fog, followed by a consideration of the causes, characteristics, and distribution of each type. This whole development is carried out in terms of the Bergen methods of air mass analysis, because these are the only methods of synoptic treatment which stress the fine observational distinctions necessary for the consideration of a meteorological element as sensitive as fog.

Part III contains a statement of the fundamental principles to be followed in fog forecasting, again in terms of air mass properties, and a brief consideration of the application of these general principles to each specific type of fog.

Part IV contains some general elementary considerations of relations between fog frequencies and type of exposure which should be noted in choosing an aerodrome site.

Abbreviations used are as follows:

R_w=relative humidity with respect to water.
R_i=relative humidity with respect to ice.
T. A.=tropical air.
P. A.=polar air.
W. A.=warm air.
C. P. A.=continental polar air.
M. P. A.=maritime polar air.
Trans. A.=transitional air.
C. Trans. A.=continental transitional air.
M. Trans. A.=maritime transitional air.
T_a=temperature of air just above ground surface.
T_g=temperature of ground (or water) surface.

PART I

NUCLEI OF CONDENSATION

The study of nuclei of condensation in the atmosphere is a problem for the physicist rather than the meteorologist. In the general condensation processes, it is the meteorological factors which play the decisive part in determining the direction the process shall take, not the nuclear factors. The whole trend at present, in the light of the increasing observational data on the conditions actually prevailing in clouds where condensation is taking place, is to postulate an ever smaller degree of supersaturation [1] in these processes. It would appear that there are *always* condensation nuclei present in the lower troposphere such that condensation begins directly or a trifle before a state of complete saturation is attained, and such that supersaturation is almost immediately dissolved. This is perhaps not the case in the upper troposphere (cirrus level) and in cumulo-nimbus convection.

For the problem of fog and low ceiling (the greatest obstacles to aviation), we are concerned primarily with the condensation processes and nuclei only in the lowest troposphere. But it is exactly in these lowest air layers, especially in populous industrial regions, that local pollution of the atmosphere results in such numbers of active condensation nuclei that the very marked effect on fog frequency, density, and duration has been observed and studied for half a century. Furthermore, since most aerodromes for commercial aviation purposes must be situated in such regions, the study of this rather local type of fog assumes a special importance. The hitherto unsolved problem of clearing aerodromes of fog by artificial means requires for its solution a much more precise knowledge of the chemical and physical properties of these nuclei than we yet possess. These considerations make it seem almost essential to commerce any general discussion of fog formation and forecasting for aviation purposes with a brief summary of our present state of knowledge of the nuclei of condensation.

The classical experiments of C. T. R. Wilson first proved beyond a doubt that nuclei of some sort are necessary for condensation to take place, by showing that in thoroughly filtered air no reasonable degree of supersaturation can produce water droplets. J. J. Thomson developed the mathematical formulæ which explained this fact as a result of the increased vapor pressure caused by the greater surface tension over the surface of droplets with decreased radius of curvature. The existence of very small droplets, such as must be the first stage of spontaneous condensation without nuclei, would require enormous supersaturation. To meet this difficulty, all theories explaining condensation have assumed nuclei of one of the three following types, or combinations of two or all three types in a single nucleus:

(1) Neutral dust particles of a size sufficiently great that the surface curvature of the particle will permit of condensation with only a moderate degree of supersaturation.

(2) Particles having an electric charge, or ions, such that the electric forces acting over the surface of the particle sufficiently counteract the surface tension to permit of condensation with only moderate supersaturation.

[1] When not otherwise specified, the degree of saturation is always considered with reference to a water plane surface, the percentage expression being R_w.

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(3) Hygroscopic particles such that the forces due to the chemical affinity of the particle for water reduce the vapor pressure over its surface sufficiently to permit of condensation at moderate supersaturation.

The first type of nucleus, the neutral dust particle, was the one assumed in the earlier theories of condensation. Aitken's so-called "dust counter" was devised on the principle that, in the event of the sudden expansion and consequent supersaturation of a sample of air, condensation will take place on all dust particles present. The "dust count" is then made from the small droplets, when they have settled. But as Hann says,[2] already in 1881 Aitken remarked that the formation of condensation nuclei might take place quite without dust, simply by the action of sunshine on certain gases, i. e., ammonia, the oxides of sulfur and nitrogen, and peroxide of hydrogen. Later experiments by Richarz, Barkow, Pringal, and Bieber confirmed the results of Aitken's early experiments indicating the important rôle played by the chemical composition of the nuclei. A. Wigand in two papers published in 1912[3] showed conclusively that *neutral* dust particles play practically no rôle at all in ordinary condensation, but that the products of combustion contain an almost infinite number of active nuclei of condensation. Wigand found with high relative humidity and a low "dust count" by Aitken's counter, that the introduction of air into the apparatus, heavily laden with dust particles from the immediate vicinity of a rug which was being beaten, had no effect whatsoever on the count, which remained low. In other words, these mechanically produced dust particles remained inactive as condensation nuclei even with marked supersaturation. He had the same result with the dust of fine ballast sand when he made a similar test in a free balloon in a cloud where there prevailed practically saturation humidity together with a remarkably low "dust count." The count was not in the least affected by the presence of so much sand dust that the silica deposit could be detected on the walls of the vessel. H. Koppe (1916–17), working on Olberg in Jerusalem, found a zero dust count by the Aitken's counter in a prevailing Sirocco so laden with dust that visibility was very poor. On the other hand, Wigand's tests made with air from a room in which a cigarette had been smoked or a candle burned for a very few moments showed an almost infinite number of particles, more than 150,000 per cubic centimeter. This proved definitely the nature of the active condensation kerns, and led Wigand to rename Aitken's "dust counter," and call it "kern counter."

Seemingly contrary testimony as to the action of ordinary dust particles as nuclei is furnished by the phenomenon observed by H. v. Ficker,[4] W. Georgii,[5] and others, that visible layers of dust haze often precede the formation of a cloud layer, and are always left behind by the evaporation of fog or cloud in still air. But that is no reason to assume, as Ficker and Georgii both do, that the visible dust or smoke particles have acted as nuclei of condensation. The same forces which tend to gather these visible particles in a definite layer, will also gather the invisible hygroscopic nuclei, presumably. And certainly the fog particles may attach dust particles to them, which will be left behind as a residue after the evaporation of the fog, without in any sense having acted as nuclei. Even in his recent book Georgii maintains that the particles visible as ordinary dust or smoke haze are active nuclei of condensation, so that haze is a real cause of fog.

The theories postulating electric forces as the essential factor in the activity of condensation kerns followed on the experiments of C. T. R. Wilson showing that with sufficient supersaturation condensation will take place on ordinary ions produced in the air by bombardment with α-particles, or other ionizing forces. He found that to produce condensation on negative ions a relative humidity of 420 per cent is required, on positive ions 790 per cent. On the basis of these results Gerdien developed his theory of the origin of thunderstorm electric potential, assuming that in strong cumulus convection there develops such a scarcity of nuclei of condensation that sufficient supersaturation occurs to permit of condensation on the negative ions, with a resulting general segregation of positive and negative electricity in distinct cloud layers. But all more recent observations have shown this theory to be quite untenable. Numerous humidity measurements by Conrad and Wagner on Sonnblick in the densest clouds have shown average values of 102.5 per cent, with an absolute maximum of 107 per cent. From these results A. Wegener[6] concludes that in cu. ni. convection from 10 to 20 per cent supersaturation may exist. More recently Hilding Köhler[7] states that of more than 4,000 humidity measurements made in clouds on Pårtetjåkko in Sweden and Haldde in Norway, four or five may have shown slight supersaturation, not more than ½ per cent. Köhler's humidity measurements were made with an Assmann psychrometer over a number of years, and every precaution taken. He considers Conrad's and Wagner's humidity measurements in detail,[8] and imputes the high relative humidities Wagner obtained to the use of the hair hygrometer at low temperatures and high humidities. He believes that because of the slowness of reaction and deposit of a thin water film on the hair in wet fogs, as well as on other theoretical grounds, its results are most unreliable under such conditions. If Köhler's measurements are correct, it means that in general supersaturation plays no important part in the condensation processes, that it is decidedly an exception in the lower troposphere. Köhler has come to the conclusion that in the ordinary condensation processes it is the hygroscopic nuclei that really count, as Aitken has found to be much more markedly the case with fog formation in industrial regions. A further consideration of their results follows below.

The only zone in which the action of the ordinary small ions as condensation nuclei may still appear reasonable is the upper troposphere, at the cirrus level. A. Wigand has found from measurements carried out in numerous free balloon trips[9] that the Aitken's kern counter gives counts of close to zero regularly in the cirrus level. On the other hand, the cirrus clouds show a density of very fine particles that must number hundreds per cubic centimeter. The only explanation Wigand can offer is that such supersaturation prevails that condensation takes place on ordinary ions. These would not

[2] Lehrbuch der Meteorologie, fourth edition, 1926, p. 16.

[3] Über die Natur der Kondensationskerne in der Atmosphäre, inbesonders über die Kernwirkung von Staub und Rauch, Met. Z. Jan. 1913; und Untersuchungen über Dunstschichten und Temperaturinversionen im Freiballon, mit Messungen der Kondensationskernzahl, Beiträge zur Physik der freien Atmosphäre, V. Band 1912.

[4] Dunstbildung aus Stratusformen, Met. Z, 1906.

[5] Ursachen der Nebelbildung, Ann. der Hyd. und mar. Met. 1920, und Flugmeteorologie, Leipzig, 1927, p. 36.

[6] Thermodynamik der Atmosphäre, p. 254.

[7] Zur Kondensation des Wasserdampfes in der Atmosphäre, erste Mitteilung, Geofysiske Publikationer; Vol. II, No. 6.

[8] On Water in the Clouds, Geofysiske Publikationer, Vol. V, No. 1.

[9] (a) Bericht uber eine wissenschaftliche Freiballonfahrt bis 9425 m. Höhe, Beiträge zur Physik der freien Atmosphäre, VI Band, 1913. (b) Die vertikale Verteilung der Kondensationskerne in der freien Atmosphäre, Annalen der Physik, Band 59, 1919.

appear in the counter, for it employs an insufficient expansion to effect condensation on ions. Between 8½ and 9½ kilometers, in fine cirrus cloud, Wigand has observed on one occasion apparently excessive supersaturation. However, measurements of supersaturation by means of wet and dry bulb thermometers at between $-40°$ C. and $-50°$ C. become less than meaningless.

Although the ordinary small ions are generally conceded now to play no part in atmospheric condensation, the large ions, or Langevin ions, whose presence and slow movement in the atmosphere has been so definitely established, are still generally assumed to be one of the important types of active condensation nuclei. Especially for fog formation has this type of nucleus been considered important. H. Bongards [10] was one of the first to try statistically to prove a relation between the density of such ions and fog formation. Assuming that the presence of such ions in the air is due primarily to the breaking down of radio-active matter, he expected to find a much smaller ion count with winds from the sea than with winds from land, for radio-active material is so much more abundant in soil than in sea water. From measurements of the products of radio activity in the atmosphere made at Lindenberg he found this to be the case, winds with a marked northerly component being much poorer in such ionic activity than those with southerly. When he found at Lindenberg a corresponding distribution of fog frequency, he concluded at once that the presence or absence of the ions as nuclei was the cause of greater or lesser fog frequency. As a matter of fact exactly the same relation should hold for the hygroscopic nuclei from industrial pollution of the atmosphere. Such nuclei even more than the large ions will originate only over land. But still more probable as an explanation of the relation between fog frequency and wind direction observed by Bongards at Lindenberg are certain meteorological factors which are considered in Part II of this paper.

In spite of the fact that condensation even on the Langevin ions requires appreciable supersaturation, and that all evidence points to hygroscopic nuclei, especially in the case of the dense low fog near large cities, the ionic theory of fog condensation has become so firmly rooted that many attempts at local fog dispersion have been based on that theory. In Germany and in the United States, at aerodromes, attempts have been made to disperse fog locally by scattering electrically charged sand, or the use of screens charged to a high potential, to clear the air of its ion content. The complete failure of such experiments to give the desired results may be regarded as further evidence against the general participation of ions in fog condensation. It is the problem of hygroscopic nuclei that must be attacked.

The markedly hygroscopic character of the nuclei is of course responsible for the density and persistence of the fogs in large cities. Due to the great numbers of these nuclei present in such localities, condensation sets in before saturation is reached, on a great number of kerns. The result is a very dense cloud of exceedingly fine particles, for no particle can grow appreciably beyond the size of its neighbors without becoming diluted to such an extent that the hygroscopic forces are weakened so that it tends to evaporate again. In a country fog, where nuclei are scarce and comparatively inactive hygroscopically, near saturation values of relative humidity are required for fog formation. There is no compelling force to keep the droplets small, so the particles are larger and comparatively few in number, and therefore the fog never so densely obscuring as the real city fog. Furthermore, as soon as the relative humidity decreases slightly the smaller droplets become unstable, and evaporate to the larger more stable drops, which quickly settle. Hence, a country fog is readily dissipated. But in the city fog all the droplets are both small and stable, so that dissipation can take place only through the evaporation of the hygroscopic droplets. Hence, such fogs once formed may persist for days with comparatively low humidity. They are frequently ended only by the blowing up of a wind which removes both fog and atmospheric impurities.

The most important investigations in more recent years of the nature and probable source of the nuclei of condensation have been made by John Aitken and Hilding Köhler. Köhler worked mostly at Haldde Observatory, in northern Norway, at 900-meter elevation so that his results may be considered to apply to condensation processes in the lower cloud levels, far removed from the industrial sources of atmospheric pollution. His work has been performed entirely within the last 10 years, and is apparently rather little known as yet. Aitken's most recent work was carried out during the preceeding ten years,[11] mostly in Scotland. It consisted to a considerable extent of laboratory experiments testing the action of artificially produced nuclei obtained from the chemical compounds always produced in the atmosphere by combustion.

The two fundamental problems which Aitken attacked in his most recent work concern the action of the sun's rays in producing hygroscopic nuclei, and the extent to which ions of one sort or another take part in the fog condensation processes. The fact that radiation fogs usually suffer a marked increase in density directly the sun's rays become active has long been known, as well as the fact that sunshine greatly increases the activity of the hygroscopic products of combustion.[12] Aitken found with his kern counter that the purest air off the sea has its kern count increased tenfold by the com-

[10] Über eine Beziehung zwischen Nebelhäufigkeit und Gehalt der Atmosphäre an radioaktiven Zerfallsprodukten, Arbeiten des Königlichen Preussischen Aeronautischen Observatoriums bei Lindenberg; IX, Band, 1913.

[11] The papers containing the results briefly mentioned here are: On some Nuclei of Cloudy Condensation, 1911; The Sun as a Fog Producer, 1912; and On Some Nuclei of Cloudy Condensation, 1916. These papers are published in the *Proceedings of the Roy. Soc. of Edinburg*, but may be most conveniently obtained, together with all of Aitken's important papers, in a one volume collection by C. G. Knott, Collected Scientific Papers of John Aitken, Cambridge University Press, 1923.

[12] Opposed to this hygroscopic explanation of fog thickening after sunrise there is the convection theory. G. I. Taylor (Quart. Jour. of the Roy. Met. Soc., Vol. XLIII) has developed quantitatively the mathematical theory of the gradual penetration upward of surface cooling and radiation fog by means of the slight ever-present mechanically produced turbulence. It is frequently assumed on the basis of this theory, though not by Taylor himself, that as soon as the sun's rays become active, convection begins and the mixing process becomes much more rapid, the fog consequently thickening. As soon as the process goes a little further sufficient warming of the cold damp layer takes place so that the fog dissolves. Captain Entwistle in a recent paper (Meteorology in Relation to the Selection of Aerodrome Sites, prepared for the Troisieme Congrès International de Navigation Aerienne) offers only this explanation of the marked maximum occurring shortly after sunrise in curves showing the diurnal variation in fog frequencies. There are both theoretical grounds and observational facts to speak against the convection theory. In the first place, considering the extreme prevailing stability and the interference to the penetration of the sun's rays in such a situation, it seems quite improbable that the sun can so quickly effect sufficient warming of the lowest air to produce even the slightest convective action. Furthermore Aitken's visibility measurements at Falkirk from 1909 to 1912 show that this thickening takes place only when the slight prevailing air movement comes from a region of marked atmospheric pollution. Under otherwise similar conditions (light winds, cloudless sky, low radiation temperatures) the visibility observations at 9:30 a. m. showed no increased obscurity when the wind blew from the NW. quadrant (unpolluted source), whereas with a wind from the SW. quadrant (polluted source) the 9:30 observations showed a visibiltity of from one-half to one one-hundredth of the 8 o'clock observations. He observed also that if *the sky remained clear* and *the winds light*, this thickened fog often remained throughout the entire day without dissolving, which likewise speaks against the convection theory. The writer of this paper has himself observed in Bergen, at the end of February, 1928, a fog which persisted for two days, thickening each day after sunrise to such a density that street traffic was demoralized and artificial lighting required for office work. At night this fog thinned to such an extent that the moon was visible through it, and in the early morning it appeared only as a rather dense smoke haze. One had at midday only to go 300 meters up any one of Bergen's seven mountains to find brilliant sunshine, clear sky, and a temperature inversion of 6° or 7° C.

It is often stated that the thickening of fog after sunrise is simply due to the lighting of fires in many homes and factories, increasing the numbers of hygroscopic nuclei rather than to the specific action of the sun's rays. But it need only be mentioned here that this thickening comes with the appearance of the sun, not before. In wintertime this is in Bergen, a good three hours after the fires are lit, in London probably a good two hours.

paratively brief action of sunshine, while air from a polluted source has the count increased a hundredfold, giving counts as high as 150,000 per cubic centimeter. Assuming that the oxides of sulphur are the most important active nuclei producers among the atmospheric pollutions,[13] he made certain laboratory tests with the sulphurous anhydride (SO_2), with the following results:

(1) SO_2 and pure air contained in a glass tube and acted on by sunshine do not produce active nuclei of condensation.

(2) SO_2 and impure air in a glass tube produce some active nuclei spontaneously but the sun's rays have little effect.

(3) SO_2 and either pure or impure air contained in a silica tube (permits entrance of ultra-violet rays) exposed to the sun's action produce great numbers of active nuclei.

(4) SO_2 and pure or impure air immediately produce great numbers of active nuclei if a small amount of an ozidizing agent (hydrogen peroxide or ozone) be introduced to the tube.

(5) An electric discharge has the same effect in producing active nuclei as the ultra-violet rays of the sun, whereas radium emanations and the radio activity of the atmosphere have almost no effect.

From these observations, in the light of the known fact that both the ultra-violet rays of the sun and an electric discharge produce ozone and hydrogen peroxide, Aitken concludes that the action of the sun as a fog producer is simply due to its action in forming H_2O_2 and O_3. These powerful oxidizers probably transform the weakly hygroscopic sulphurous anhydride to the extremely hygroscopic sulphuric anhydride (SO_3). The same will hold for the nitrous and nitric anhydrides or the phosphorous and phosphoric anhydrides, in so far as they are present in the products of combustion. From the extreme numbers of nuclei produced by a very small quantity of SO_3, and from the large sulphur content of coal, Aitken shows that in the big industrial regions enough of this pollution is poured into the lower atmosphere to affect very wide areas to a marked extent.

It is quite possible that country fogs also depend on the same nuclei, for in sections remote from the pollution areas their count is of course greatly reduced. Hence, they are unable to effect turbidity of the density of fog before they have grown to such a size that dilution has greatly weakened the hygroscopic forces. Thus to form a visible fog, near saturation humidity is required, the particles then behaving as if formed on almost neutral nuclei. The settling of these large particles in the dissolution of such a fog is in that case one of the principal forces acting to clear the air of such impurities.

In answer to the frequently made charges against his methods, that the nuclei he counted in his tests showing such very high kern counts were nothing other than ordinary ions, Aitken prepared tests to determine the size[14] of the active nuclei produced by different processes, and the rôle played by ions of one form or another. Nuclei sizes were determined simply by clearing the sample of air, with repeated expansion showers, of all nuclei that would act first at 2 per cent expansion, then at 4 per cent, etc., each greater expansion giving the count of a smaller nucleus. He made the following observations:

(1) The purest air obtainable at low levels (Loch Awe, Scotland, NW. wind) seldom contained nuclei requiring more than 4 per cent , never more than 6 per cent expansion to act.

(2) Action of sunlight or electric discharge on SO_2 for any appreciable time gave only very numerous large particles, all acting at 2 per cent.

(3) Ions produced by radium, thorium, or the burning of hydrogen in pure air, all processes giving great numbers of ions, in no case became active at less than 25 per cent expansion.

(4) In impurities produced by the usual smoke pollution, as well as in the products driven off by extreme heating of any solid matter, there were both large and small nuclei produced, requiring up to 20 per cent expansion. These small nuclei will disappear after a time, giving larger nuclei. Evidently they combine, perhaps under the influence of electric charges.

From these observations Aitken concludes that there is no evidence that ions spontaneously combine to give agglomerations active as nuclei of condensation, but rather to the contrary. If they did so combine, pure air in nature should contain smaller nuclei representing intermediate stages of ion combination between the nuclei requiring 4 per cent expansion and the real ions requiring 25 per cent. It is possible, however, that the ions attach themselves to the small particles produced by heat and chemical action, helping to effect their agglomeration to larger particles. But that they can not act alone, however great their density, is shown by (3) above.

The work of Hilding Köhler[15] is along entirely different lines. His observational material, obtained chiefly on Haldde, is of four kinds, namely:

1. Numerous humidity and water content measurements in cloud fog.
2. Microphotography of fog-frost deposits, snow crystals, and ice clumps.
3. Microscopic and optical measurements of size of fog or cloud elements.
4. Chemical analyses of the salt content of fog-frost deposits.

His observations were taken for the greater part at temperatures under 0° C., the lower extreme being −28° C.

He made the following principal observations, chiefly at 900-meter elevation (Haldde), but to a lesser extent also at 1,850 meters (Pårtetjåkko):

1. R_w rarely exceeded 100 per cent, never by more than one-half per cent; R_e, on the other hand, was frequently greater than 100 per cent.
2. Fog-frost deposits, at whatever temperature laid down, showed clearly under the microscope that they were formed by the deposition and freezing of supercooled

[13] In accord with the earlier experiments of Aitken and others, and several special investigations of London fogs, namely: F. A. Russell, Über den Londoner Nebel, Met. Z, 1889; Brodie, Fog in London, Quart. Jour. of the Roy. Met. Soc., XVIII, 1892; W. J. Russell, Stadtnebel und ihre Wirkungen, Met. Z, 1892.

[14] By the "size" of a nucleus of condensation Aitken means not the physical dimensions, but simply its readiness to act. Thus a very small particle of SO_2 is "larger" than a neutral dust particle of much greater mass. Since ordinary ions require a 24 per cent expansion of saturated air (R_w=420 per cent) before they can act as nuclei, it is obvious on the face of it that they can not be the kerns counted by Aitken's apparatus, in which the expansion is always kept under 20 per cent unless it is desired to count ions. Futhermore, the large Langevin ions are never found in the atmosphere in numbers of the same order of magnitude as Aitken's and Wigand's kern counts in polluted air.

[15] Köhler's papers are scattered through several publications, but since they all deal with one phase or another of the condensation problem it is deemed best to give the complete list here:

(a) Studien über die Nebelfrostablagerung auf dem Pårtetjåkko, Stockholm, 1919.
(b) Zur Kondensation des Wasserdampfes in der Atmosphäre, Met. Z, 1921.
(c) Zur Kondensation des Wasserdampfes in der Atmosphäre, erste und zweite Mitteilungen, Geofysiske Publikationer, Oslo, Vol. II.
(d) Über die Tröpschengrösse der Wolken und die Kondensation, Met. Z, 1921.
(e) Eine Quantische Verteilung von Materie in der Atmosphäre, Met. Z, 1922.
(f) Wasser oder Eis über die Grösse der Wolkenelemente in einigen verschiedenen Wolken, Met. Z, 1923.
(g) On Water in the Clouds, Geofysiske Publikationer, Oslo, Vol. V.
(h) Über Tropfengruppen in Wolken, two papers in Met. Z, 1925.
(i) Untersuchungen über die Elemente des Nebels und der Wolken, Meddelanden från Statens Meteorologiska-Hydrografiska Anstalt, Stockholm, 1925.
(j) Zur Thermodynamik der Kondensation an hygroskopischen Kernen und Bemerkungen über das Zusammenfliessen der Tropfen, Meddelanden, etc., Stockholm, 1926.
(k) Über Koagulation in der Atmosphäre, Met. Z, Feb. 1927.

droplets, not by sublimation in crystalline form. Furthermore, the microscope showed that precipitation in the solid form, apart from hail, had three forms—(*a*) fine snow crystals, the product of sublimation; (*b*) snow crystals more or less covered and melted by the deposition and congealing of supercooled droplets; and (*c*) ice clumps produced by the meeting and congealing of two or more supercooled droplets.

3. On the average, 13 out of 20 fog droplets belonged in a series whose sizes increase as 1;2;4;8;16;32, the most frequent size of droplet found, 0.07 millimeters, being of this series, which he called the 7 series. He also found traces of an 8 series. From certain coronal characteristics in such clouds, which he detected also in coronas produced in a. st. and ci. clouds, he concluded that the same series exist among supercooled droplets in the highest cloud levels.

4. Numerous tests applied to the fog-frost deposits showed an almost constant chlorine amount, 3.59 milligrams per liter, just 1/10000 the concentration in sea water. Quantitative tests for magnesium showed the same ratio to chlorine amount as exists in sea water, and the presence of calcium was proved qualitatively. Köhler tried, by choosing the fogs whose deposits he tested according to the size of the prevailing droplets, to test the sea-salt content of each droplet series, but he came to the conclusion that only the 7 series contributed actively to these deposits. He found that pure snow flakes had no chlorine content, those with frozen droplets attached showed chlorine amounts increasing with the number of droplets, while the ice clumps showed the same chlorine amounts as the fog-frost deposits.

From these observations and certain supporting evidence which can not be considered here, Köhler came to the following general conclusions concerning the nature and distribution of nuclei and the condensation processes in clouds:

1. The common nucleus of condensation is ordinary sea salt (moderately hygroscopic due to the presence of magnesium chloride). This must certainly be the nucleus for the droplets of the predominating 7 group, possibly for others. The constant concentration of sea salt in all drops of this group is to be explained on the assumption that by some selective process salt particles or droplets of one particular size are driven from the sea. Due to their hygroscopic action, they are always present in the air as tiny droplets which with R_w close to 100 per cent grow to a definite size (and concentration), and thereafter grow only by the joining of droplets of the same size to give the geometrically related 7 group. No supersaturation is required. Presumably in regions far removed from the sea, such nuclei are less predominant. This theory seems to be supported by observations of Kinch (at Cirencester, England, 1885–86), in which he found winter rain water tested 3.58 milligrams of Cl. per liter, approximately Köhler's value, while A. Defant at Vienna, an inland location, found a Cl. quantity only two-thirds of these values. Furthermore, Köhler showed by analysis of Defant's cloud particle measurements that while the 7 group was distinctly present it was not nearly so predominant as on Haldde.

2. The condensation process must take place for the most part in clouds of supercooled droplets, which are able to join, at least up to a certain size, without congealing. Above this size they will congeal, as shown by microscopic study of ice clumps, the principal form of intense precipitation on Haldde.

3. The sublimation process, to form true snowflakes, takes place only on frozen droplets, as nuclei, with $R_e > 100$ per cent and $R_w < 100$ per cent. The freezing of the supercooled droplets which furnishes nucleii is probably effected by marked turbulence. A. Wigand has concluded [16] that the formation of ice crystals (needles) by sublimation takes place in the higher clouds only on frozen droplets as nuclei when $R_w > 100$ per cent. Probably the same holds for surface fogs composed of ice needles sometimes observed at very low temperatures. Hail and graupel, the products of true cu. nb. convection, are no doubt the results of an appreciable degree of supersaturation.

From this brief summary of investigations of nuclei of condensation, it becomes quite evident that everything points to the importance of the hygroscopic forces in the condensation processes. In view of the very incomplete state of our present knowledge of the subject, it is up to the chemist to make further investigations and to suggest possible means of combating the fog nuisance at least locally.

PART II

FOGS AND HAZE, THEIR CLASSIFICATION, CAUSES AND FAVORING SYNOPTIC SITUATIONS

In passing from the consideration of the nuclear factors of fog formation to the meteorological factors, it is assumed that there are always sufficient nuclei present to effect condensation when saturation vapor pressure is reached in the lower stratosphere. All observation seems to justify this assumption. It follows that the meteorological factors are decisive in the determination of fog distribution, and must therefore be made the basis of any fog classification.

During the past 20 years there have been undertaken four general surveys of the subject of fog. One of these by W. Köppen [17] (1916–17), was a very illuminating climatological study of fog distribution for all parts of the world for which he could obtain reliable data. But it was in no sense intended either as a classification or an explanation of fog formations.

Another fog investigation is that of G. I. Taylor,[18] who treated rather fully smoke haze, sea fog formations, including interesting aerological material obtained on board the *Scotia* near Newfoundland, and especially radiation fog together with certain theoretical considerations of conduction of heat, molcular diffusion of vapor, and turbulence effects.

A third fog investigation, by W. Georgii [19] (1920), contains much excellent aerological data from the German network of stations during the latter part of the war, concerning inversion surfaces, haze, and radiation fogs. But other types of fog are rather neglected, especially the maritime types. They are all included in two rather weakly treated classes, i. e., Mischungsnebel, and a very dubious Wogennebel,[20] a class which later (1927) Georgii very wisely neglects to mention at all, apparently including it under Mischungsnebel. The last investigation is one begun by Calwagen at Bergen,

[16] Untersuchungen über Dunstschichten, etc., Beiträge zur Physik der freien Atmosphäre, Vol. V, p. 186.

[17] Landnebel und Seenebel, Annalen der Hydrographie und Maritimen Meteorologie; Part I, 1916; Part II, 1917.

[18] The Formation of Fog and Mist, Quart. Jour. of the Roy. Met. Soc., vol. 43, 1917.

[19] Die Ursachen der Nebelbildung, Parts I and II, Annalen der Hydrographie usw, 1920, and summarized in a somewhat modified form in his Flugmeteorologie, Leipzig, 1927.

[20] Taken from older authorities. See H. Elias, Die Entstehung und Auflösung des Nebels, 1901.

which was most unfortunately never completed, due to his untimely death. However, there exists in manuscript form the brief working outline and classification which he had developed, however incomplete he may have regarded it. Calwagen's Classification is the only general one which is based throughout on the concepts of the Bergen school. It is, however, in the form in which he left it, rather incomplete in that it considers only maritime types and littoral (Scandinavian west coast) types. He does not consider the continental types. Furthermore, Calwagen makes the geographical classification the primary, the analytical subsidiary. Since, however, the discussion here is intended to be quite general, and geographical influences are innumerable, the primary classification will be analytical, the geographical and seasonal modifying influences being treated as subordinate.

All fogs may be grouped in two classes, quite distinct both as to processes of formation and characteristics when formed, namely, (1) *Air mass fogs*, and (2) *Frontal fogs*. Frontal fogs occur either within or immediately before or immediately following the zone of transition (front) between two air masses of markedly different characteristics. They are dependent upon the meteorological processes taking place along the front for their existence. It follows that fogs of this type occur in rather narrow zones and are of a transitory nature, moving with the fronts. Even in the case of a quasi-stationary front such fogs are not long persistent in one locality, for such a front is always subject to passing displacements which cause quite variable weather along its course. It follows that all the more extensive and persistent fogs belong to the first class, which shall be considered first.

Air mass fogs are fogs which occur within and often throughout a given homogeneous air mass as a result of the meteorological processes affecting the air mass through out its horizontal extent. The term *air mass* is used in the sense of the Bergen School [21] to refer to any extensive body of air which is horizontally homogeneous, the result of the extended currents of flow prevailing in the different branches of the usual circulation, which permit of a similar life history throughout the air mass. No detailed discussion of air masses can be undertaken here. Three general types must be recognized in a discussion of fog formation:

(1) Tropical Air (T. A.) = air masses of tropical or subtropical origin.

(2) Polar Air (P. A.) = air masses of polar or subpolar origin, fresh enough to still have the P. A. instability characteristics (see Bergeron, Wetteranalyse, pp. 34–36). P. A. masses are of two types, continental (C. P. A.) and maritime (M. P. A.), according as their life history since leaving their source has been primarily over land or over open sea.

(3) Transitional Air (Trans. A.), Calwagen's terminology, former polar air, in the usual Bergen terminology = air masses originally of P. A., but which in the process of aging have lost the instability characteristics in the lower layers but not in the upper. According as the aging has taken place over land or over open sea we have again the important continental (C. Trans. A) and maritime (M. Trans. A.) distinction.

[21] For a thorough treatment of air masses, their nature, the reason for and proof of their existence, their kinds, and the characteristic properties of each kind at different levels, see Bergeron's Über die dreidimensional Verknüpfende Wetteranalyse, Oslo 1928, No. 6 in Vol. V of Geofysiske Publikationer, pp. 32–68. This paper of Bergeron's contains the gist of all the practical working concepts of the Bergen School, together with theoretical considerations of the processes leading to the genesis and disintegration of fronts and the modus operandi of these processes in the scheme of the general circulation of the northern hemisphere. Hereafter reference to this paper will be made simply as Bergeron, Wetteranalyse.

A consideration of the properties of these respective air masses only in so far as they affect fog formation will be touched upon briefly in the discussion of each fog type.

OUTLINE OF AIR MASS FOG AND HAZE

I. Advection types.
  A. Types due to the transport of warm air over a cold surface.
    1. Monsoon fog (Calwagen's Monsundimma).
    2. Sea fog occurring near contrasting water temperatures.
    3. Tropical air fog (Calwagen's Varmfasdimma).
    4. Tropical air haze.
  B. Types due to the transport of cold air over a warm-water surface.
    1. Arctic sea smoke (Calwagen's Sjörök).
    2. Autumn early morning steam mists over lakes, rivers, etc.
II. Radiation types = characterized by a marked inversion and clear skies above. (Only in Trans. A., over land.)
  A. Ground fog, characterized by a surface inversion (Georgii's Senkungsnebel).
  B. High fog, characterized by an upper inversion (Georgii's Strahlungsnebel).
  C. Inversion haze.
III. Type characteristic of maritime transitional air when cooled over land = Maritime fog.

I. ADVECTION FOGS

The advection types, since they all require a considerable transport of air, are characterized by a certain amount of wind, in contrast to the radiation types, which in general are densest with almost complete calm. In the first class of advection fogs the fundamental process leading to condensation is the raising of relative humidity by cooling, the specific humidity being constant. In the much less important second class the fundamental process is the raising of the relative humidity by the addition of moisture and hence increased specific humidity, the temperature being somewhat increased.

Each kind of fog or haze will now be considered in some detail.

A. TYPES DUE TO THE TRANSPORT OF WARM AIR OVER A COLD SURFACE

1. Monsoon fog.—Köppen came to the conclusion from his analysis of the geographical and seasonal distribution of fog, that fog is fundamentally a *coastal* phenomenon, most frequent over the mainland in fall and winter, over the sea in spring and summer, hence most frequent over those regions which are coldest relative to their surroundings. Since it is exactly this same seasonal temperature contrast between land and water surfaces which is responsible for the monsoon circulation causing such a fog distribution, the term "monsoon fog" has been applied to those fogs formed by the transport of warm continental air in summer over a cold-water surface. The fog formed by the reverse process in winter is not included in the same class, because there the radiation processes seem to be equally important in effecting the air mass cooling. Hence such fog is treated as a special type, type III in the above outline.

The important factors in the formation of the monsoon fog are: (1) Marked temperature contrast over land and sea, (2) moderately high specific humidity content in the

warm air mass transported from land, and (3) sufficiently weak cyclonic activity so that the monsoon circulation is not interfered with. The air mass which is transported from the land to the sea, in which the fog formation occurs, may be either real T. A., or as more usually is the case, simply C. Trans. A., which in the summer time may be quite as warm as T. A. All air masses remaining long over a continent in summer become so heated and modified as to rapidly lose their former distinguishing characteristics.[22]

These three conditions are most favorably present in the case of the California coast fog. The importance of the monsoon element in this case is evidenced by the fact that it is the daily sea breeze which brings the fog on shore regularly each day. On the other hand pilot balloon observations have failed to show the presence aloft of a return current of warm air from the land to the sea. If this return branch of the typical monsoon circulation is really missing, then the California fog is rather a sea fog formed over the cold water which wells up off the coast. In this case the warm air mass whose cooling produces the fog is simply brought with the general air drift from the warmer waters farther west. However, it must be remembered that simply because the general air drift is from the west the westward branch of the monsoon circulation aloft will be much less prominent than the eastward flow at the surface and probably often quite obscured.

The monsoon type presents a much more interesting and important problem in places where the irregularities contingent upon cyclonic activity are present. Two such localities will be considered briefly, and one particular instance of such a fog discussed in some detail.

On the New England coast, especially from Cape Cod northward, there exists in the late spring and early summer the marked temperature contrast which is so favorable to the formation of monsoon fog. The effect of the low-water temperatures here is seen in the high summer fog frequencies [23] of the outlying stations. However, this region is one of so much cyclonic activity that the regularity of the California coast phenomenon is entirely lacking. The winds have prevailingly a westerly component, so that the fog is not brought so much on shore. It is only occasionally in a more or less stable anticyclonic situation that the daily monsoon influence becomes clearly evident.

On the northern European coast, especially off the Scandinavian peninsula, conditions are best suited for the development of widespread monsoon fog of irregular occurrence. In marked contrast to the North Atlantic coast of North America, it is a region of degenerating cyclones, and of frequent general stagnation of the atmospheric circulation. The result is that in summer time, under the influence of a stagnant moribund cyclone or series of such cyclones passing slowly along a quasi-stationary weakly frontal zone, there may be established general persistent air drifts which will bring warm continental air westward over the Norwegian and North Seas for many days in succession. Under such conditions monsoon fog of the most aggravated type will develop. A change in the direction of air drift will result in an innundation of coastal regions on the continent by the fog. A brief discussion of a specific instance of such a fog, which the writer of this paper has studied in detail, should at this point prove both interesting and instructive as to the sort of synoptic situation favoring its development.

[22] See Bergeron, Wetteranalyse, p. 36.

[23] See Köppen, Annalen der Hydrographie, etc., 1916, p. 254.

From June 27 to July 10, 1927, the occluded and slowly filling disturbances approaching Europe from the Atlantic moved very slowly inland across England, south of Scandinavia and the Baltic, to southern Russia, along a weak and diffuse quasistationary front. Along this front there was a continuous trough of low pressure. North of this trough there prevailed light easterly winds, clear skies, and hence strong insolational heating over the continent. Thus is established a current of very warm continental air from the interior of Russia over the northern and central Scandinavian peninsula on to the Norwegian Sea. This current became particularly marked from June 28–30, July 2–4, and July 8–10.

During these periods humidity determinations at the coastal stations showed rather high values of relative humidity, which indicated that the moisture content of the outflowing warm air masses was extremely high, at least in the lower levels. The influence of the warm outflow was felt very strongly at Jan Mayen, and less markedly even to the coast of Greenland. On June 30 the temperature on Jan Mayen reached 12° C., which is 9° C. above normal, and 10° C. above the probable surface sea temperature, an exceedingly large difference for a truly maritime station.

These extensive warm air masses of high absolute humidity become stagnant and rapidly cooled over the cold sea surface. Probably in the northern portion the cooling process is aided by mixing with cold P. A. from the anticyclonic region to the north. On July 1 fog is reported from Jan Mayen and Iceland stations, and in the following days dense fog is reported from Greenland to Norway and from Spitzbergen to the English Channel. Vessel reports show the fog to be dense not only on the coasts, but over the entire intervening sea, rendering impossible the maintenance of numerous steamship schedules. This great mass of chilled and foggy air simply extends in one direction or withdraws in another according to the prevailing winds, which are always light. For more than a week there was no marked change in the situation, the supply of warm air over the sea being maintained continuously. After July 10, however, a marked change took place in the prevailing situation. The last disturbance to pass along the weak front mentioned above developed enough energy to render it unstable. The outflow behind this disturbance brought the foggy air southward, the persistent trough of low pressure disappeared, and immediately the outward flow of continentally warmed air ceased. The normal summer flow of air from the sea to the warmer land surface was reestablished, which on July 12 and 13 brought the foggy air masses onto the coast of Europe from western France to northern Norway. The entire coast region as far as 100 to 200 miles inland was densely fogbound. Especially over Germany the southward movement of the foggy air mass behind the concluding disturbance brought a dense fog invasion which extended in a broad tongue quite to the Alps. But so extensive had been the fog formation during the preceding weeks that in spite of such widespread transport of the foggy air masses to land, the situation over the sea was not improved. The Norwegian Sea, North Sea, and much of the coast of Europe remained foggy until July 15–16, when the southeastward advance of a fresh unstable M. P. A. mass under the influence of a vigorous disturbance developing between Iceland and Jan Mayen finally displaced the stagnant foggy air mass.

Two characteristics of monsoon fog as observed over the Norwegian Sea and Scandinavian coast deserve

special mention here. (1) Over the open sea this fog is never of uniform density, but lies usually in dense banks with relatively broad and clear spaces between. These fog banks extend at right angles to the direction of the motion of the wind, which is always slight. There seems to be no very satisfactory explanation offered for this phenomenon. Probably the cooling of the air takes place over the cold water in the surface layers, and spreads slowly upwards with fog formation by turbulence effects, according to the theory of G. I. Taylor.[24] The wind is usually light and unsteady, coming in irregular puffs. Quite possibly the increased turbulence contingent upon such a wind puff so accelerates the mixing process that potential fog, so to speak, is released throughout the accelerated body of air, giving a fog bank. However, no attempt has been made to correlate the horizontal extent of such a wind puff with that of a fog bank. They may not be even of the same order of magnitude. The fact that the cooling of such an air mass actually takes place from the bottom, spreading upwards by dynamic turbulence, rather than throughout the mass by radiation, is shown by the extremely stable stratification which develops. The theoretical aspects of this question are considered further under radiation fogs. (2) When this type of fog is brought over a mountainous coast, as at Bergen, under the influence of a light afternoon sea breeze, it pours over the outlying lower mountains in advancing cataracts, but rapidly evaporates as it comes inland, so that as long as the sun is above the horizon, the visible fog does not reach as far inland as Bergen. But towards sunset the moisture which has been coming in invisibly, begins to condense and appear as fracto cumulus at from 400 to 600 meters' elevation on the sides of the higher mountains inland from Bergen. After sunset there rapidly develops a dense stratus which later in the night often becomes thick fog down to the surface of the fjords. Usually this fog dissipates soon after sunrise the following day, unless it is a case of a real invasion by foggy air masses as a result of general prevailing winds, when it may last for days as in the case discussed above.

2. Sea fog.—Just as monsoon fog is caused by the cooling over a cold water surface of warm air from land, so can fog be formed by the transport of air from a warm water surface to a cold water surface, with subsequent cooling. This is perhaps the commonest cause of fog formation over the open sea far from land, so the name sea fog has been given it. This form of fog is favored by the same conditions as monsoon fog. The necessary temperature contrasts in surface sea temperature are found especially where warm and cold surface ocean currents come into close contact. Sufficiently high humidities are always found in the lower layers of air masses which have been resting long over the sea. Finally the prevalence of light to moderate winds sufficient to effect the transport of air is necessary, but light enough so that the air can become thoroughly cooled over the cold surface. The air masses most frequently fulfilling these conditions are M. Trans. A. masses, for usually in periods between marked cyclonic activity in middle latitudes such air masses prevail, being the aging relics of the P. A. outbreak which ended the preceding cyclone series.

Special mention should be made here, for the sake of completeness, of the case when the air mass transported from warmer to colder water is really the W. A. or T. A. in the warm sector of a vigorously developing cyclone. Then it is possible to get fog even with high winds. But in that case it is the T. A. characteristics of the air mass which are primary, the particular local temperature contrast not being in the least essential. Hence such fogs belong under the more general T. A. type, not under sea fog.

The best known producer of sea fog is the Labrador Current.[25] The steep horizontal temperature gradient on the sea surface between this current and the warm waters of the Atlantic a little farther south (the Gulf Stream) is extremely favorable to fog formation. The regions of greatest frequency are over the cold sea north of Iceland toward Spitzbergen and westward to Greenland, and from the Newfoundland banks west-southwestward. In these regions any wind with a southerly component crosses closely crowded sea surface isotherms, hence rapid air mass cooling follows, while in summer also a west wind brings warm air from the continent to form monsoon fog over the Newfoundland banks region. Unlike monsoon fog, sea fog is quite frequent in winter, for the temperature contrast between sea currents persists throughout the year. But sea fogs also have their greatest frequency in late spring and early summer, for the temperature contrast is greatest then. Southern waters are more rapidly warmed than northern, especially due to the large amount of floating and melting ice in the currents of northern origin. The Labrador Current is famous for the icebergs it brings down in late spring and early summer. Furthermore, air temperatures are higher in summer, the specific humidity greater, and consequently cooling through the same temperature interval produces more condensation than in winter.

The extreme case of summer cooling by ice occurs over the Arctic seas. Over the drift ice on the North Siberian Shelf, according to the observations of Professor Sverdrup,[26] the isothermal cooling by the ice in summer frequently extends to 200 meters or more. Fog is very frequent in this cold air stratum, reaching its maximum in August, when it is prevalent 37 per cent of the time, being most marked in the early morning. During the cold season, October to April, fog is prevalent but 2 to 3 per cent of the time. The big increase is from May to June, the big decrease from September to October. During the cold season, in calm weather, very great cooling of the lowest air layers over the solidly frozen and snow-covered sea surface takes place by radiation in the continuous absence of the sun. But the absolute humidity of the extremely cold air is so low that the amount of condensation attendant upon supersaturation is not sufficient usually to give fog, but merely a very tenuous turbidity which has been designated in the *Maud* observations as haze and which is characteristic of the coldest weather.

Sea fog, like monsoon fog, is often characterized by successive dense banks with clearer intervals between, when the winds are light. Presumably the reason is the same, for the physical processes in the formation of these two fogs should be identical.

3. *Tropical air fog.*—Tropical air fog is the perfectly general term applied to the fog formed in the lower levels of a warm air mass moving from lower to much higher

[24] The Formation of Fog and Mist, Quart. Jour. of the Roy. Met. Soc., Vol. XLIII, 1917.

[25] The Newfoundland banks fog has been especially studied by G. I. Taylor on board the *Scotia*. He has obtained some aerological data in the region, and has shown how, in one instance, the past history of the foggy air mass in its movements from warm to cold surface back and forth is reflected in the vertical temperature gradient and humidity distribution in the mass.

[26] The meteorological observations taken on the *Maud* expedition, 1922-1925, have not yet been published. Professor Sverdrup, who is at present working them up, was kind enough to show the observational data and frequency curves for fog, and to discuss the prevailing meteorological conditions.

latitudes. Monsoon and sea fogs are a result of the cooling of an air mass in its lower layers due to special local surface temperature contrasts. Tropical air fog is the result of cooling due to the general poleward temperature decrease of the earth's surface. By reason of the great variety of geographical, seasonal, and individual modifying influences that affect this phenomenon in different parts of the world, this discussion can not be made perfectly general. The phenomena of tropical air fog and tropical air haze are considered as they characteristically appear from western Europe northward. Thereafter follow certain remarks pertinent to conditions in the United States.

Any air mass which is displaced far to the north over an increasingly cold surface gradually acquires certain characteristics.[27] It becomes markedly warmer at all levels than its surroundings. Since the cooling takes place especially in the lowest layer, working upwards by turbulence, the tendency is to increasing thermal stratification, with the formation even of small inversions. Such an air mass usually leaves its source, the Azores HIGH, thermally quite stable, and rather dry. Gradually the cooling by contact with the cold surface below and by radiation above increases the relative humidity in the lower levels to near saturation values, so that eventually condensation takes place.

The quickness with which saturation is reached is doubtless accelerated by evaporation from the sea surface in the earlier history of the air mass. An inland station probably rarely gets real T. A. fog unless the air mass has previously traveled over water, or has been subjected to the unusually strong cooling of a snow-covered land surface or at least a land surface which has recently been covered by an anticyclonic air mass very much cooled in its lowest layers. Mixing with the cold remnants of such an air mass, usually saturated, is doubtless often a contributing factor.

The condensation products are of necessity stratiform, ground fog or low stratus which may eventually give a thick fine drizzle, and often at the inversions above, they are the wave formations, st. cu. or a. cu. Thus a strong southerly surface air current coming into northerly latitudes is characterized by fog, low stratus, and drizzle, which may be of very wide extent, depending on the current in which it is found.

Certain characteristics of this type of fog deserve special mention. In the first place, it does not usually attain the extreme density of the radiation fogs, being rather in the nature of a dense fine drizzle. However, over cold water (see sea fog, above), a snow or ice covered land surface, or when the stratified air flow is forced upward orographically, there may be dense fog produced. In general a T. A. current in winter time at more than 45° latitude must be characterized by a strong flow, otherwise it would not have reached there. Surface winds in such a current are usually fresh to strong, hence T. A. fog is characterized by its occurrence in fresh winds, sometimes even strong or of gale force. It is the only *air mass* fog which can occur in strong winds. Only the extremely stable stratification of the T. A. mass prevents its rapid dissipation by turbulence. Finally, this type of fog occurs on land, especially in the foremost or advance portion of a newly established T. A. current, for here the warm air is usually passing over a surface where anticyclonic conditions have recently prevailed, and which has therefore been cooled by radiation processes. Furthermore, there is doubtless much mixing with the cold and usually saturated (by warm front rain) remnants of the retreating cold air mass which have been left in valleys or behind mountain ranges, etc. Hence, the most marked T. A. fog occurs in a broad well defined zone advancing with the warm current itself. Rarely over a continent, even in winter, is fog or drizzle reported from a station which has been in the warm current for more than 24 hours, though over the sea this may happen.

The seasonal influences on this phenomenon are very marked, due to their effect on T. A. characteristics. The insolational heating of a continental surface in summer is such that even an air mass of subtropical origin may be further heated over the Continent of Europe to such an extent that it becomes conditionally unstable and may even give rise to thundershowers. Naturally the fog and stratus products of the wintertime thermal stratification are quite out of the question under such conditions. Over the sea, however, it is possible in summer as well to get the typical tropical air fog and drizzle, but it is much less pronounced than in winter, because the poleward temperature gradient is so weakened. This means (1) that the flow of air currents is weakened (smaller displacements occur), and (2) that the same displacement produces less cooling. The really significant summer types are the monsoon fog and sea fog discussed above, for which the continental heating acts most favorably.

4. *Tropical air haze.*—Air masses of subtropical origin are characterized by comparatively poor visibility even before condensation products begin to form. Over western Europe this characteristic turbidity is such that even under the most favorable conditions (on Scandinavian mountain stations) the visibility can not exceed about 30 kilometers, whereas air masses of polar origin under the same conditions, if the visibility is unobscured by condensation products, give visibilities of from 150 to 300 kilometers. This turbidity is so characteristic of T. A. masses that Bergeron considers it as the most conservative distinguishing property of air which is really of subtropical origin, and calls it opalescence. Its opalescent character is shown by the fact that outstanding objects (mountain ranges, etc.) when seen through it by scattered light appear blue, and at only moderate distances become indistinct in a bluish haze, while the sun as seen through it by direct light is distinctly red. This opalescent turbidity is the effect of the selective scattering of the short-wave elements of the sun's light by numerous extremely small dust particles. That these particles are uniformly diffused throughout the air mass in spite of its marked stratification proves that the diffusion occurred very early in the history of the mass, presumably at its source. Supposedly it became thoroughly infected with the dry dust blown up in dust storms which are so frequent over the extensive desert regions of northern Africa, and which affect the dust content even of the Azores HIGH. In the slow journey northward all the larger dust particles gradually settle out, leaving only the very smallest, which produce opalescence. As soon as the condensation processes begin, a washing out of these small particles is initiated. Hence tropical air haze is most pronounced in summer, especially over the continents, where the T. A. masses remain dry, and the continued infusion of dust, at least in the lower levels, may occur.

The extreme case of this type of poor visibility occurs with the dry laden sirocco from the deserts in Asia Minor, and the true desert sand storms, which as suggested, are probably the obscuring phenomena whose

[27] For a complete discussion of the influences at work on such an air mass, and the characteristic effects produced, see Bergeron, Wetteranalyse, pp. 36–38.

last remnants persist throughout the life history of the T. A. mass as opalescence. Every intermediate degree of visibility is possible at one point or another in the history of the T. A. mass.

Over continental Europe the effect of the continued infusion of dust and smoke in summer time added to the effect of true opalescence, may reduce the visibility in dry weather to a very few kms. Shimmering and other optical effects of strong local heating contribute further to the uncertainty of the visibility.

The poor visibilities that accompany T. A. at all levels are indicated by the visibility observations of W. Peppler.[28] He finds that from the high stations Hochenschwand and Grosser Belchen the frequency of good visibilities toward the Alps in the south falls to almost zero with winds between SE. and SSW. This is in spite of the fact that such winds are Föhn winds, usually with clear skies and low humidity, both conditions favorable to good visibility. The probable explanation is to be found in the fact that such winds usually bring T. A. from the south, with its obscuring opalescent haze or dust.

The properties of T. A. masses over the United States depart considerably in some respects from the characteristic European type just considered. The occurrence of parallel phenomena is scarcely to be expected. The principal modifying influences are two: (1) The source of such air instead of being an extensive dry continental region or a great maritime anticyclone of dry descending air is rather the moist and often thermally unstable air of the Gulf of Mexico. To a certain extent, however, especially in summer, such air may be drawn from the hot and dry southwestern part of the United States and northern Mexico. But, in general, instead of increasing land areas to the south they are decreasing. (2) The United States is situated so much further south than the regions considered above that the T. A. currents have had much less latitudinal displacement and cooling, and are much more frequent. It is quite possible that the characteristic fog and drizzle is not yet developed. It seems to be a fact that comparatively fine weather is often experienced in the eastern United States *after* the passage of the warm front, the only fog being of the prefrontal type to be considered later. At all events, no certain conclusions can be drawn as to the occurrence of the characteristic T. A. phenomena in the United States without more precise observations in conjunction with an accurate air mass analysis.

B. TYPES DUE TO THE TRANSPORT OF COLD AIR OVER A WARM WATER SURFACE

Fogs of this type are of no practical importance, for by their very nature they are unable to become dense or to persist. They are interesting theoretically because they form in a situation which must of necessity be unstable and evanescent, and because undue importance has frequently been attached to this process in theories of fog formation.

1. *Arctic Sea smoke* (*Calwagen's Sjörök*).—In the Arctic regions the rising of clouds of vapor, or steaming, over the open sea has often been observed in the presence of very cold air. The phenomenon is seen best when the sudden opening of a rift in a solidly frozen sea surface exposes water to an atmosphere which has been cooled to an extremely low temperature by radiation over the continuous snow surface. Then the steam may rise in such clouds as to resemble the smoke clouds of a conflagration. This phenomenon is simply due to the fact that the vapor pressure over the relatively warm sea water is so much greater than the saturation pressure in the extremely cold surface air that evaporation takes place at a rate which immediately produces supersaturation, and condensation as steam, or sea smoke fog, exactly as occurs over hot water in an ordinary atmosphere. The fact that this process renders the cold air mass unstable wherever it occurs is shown by the rapidity with which such vapor rises and dissipates. Therefore sea smoke can develop into a dense and persistent fog only under exceptional circumstances. The following conditions are necessary:

(1) There must be a very stable stratification, presumably a marked surface inversion in the cold air mass to begin with, otherwise the heating from the warm water surface must quickly render it so unstable that the fog will rise as smoke and dissipate. Such an inversion can not form over warm water. The air must be recently brought from a very cold land surface without the destruction of the inversion. This is best effected by a gravitational flow and spreading out of radiation cooled air over a warm water surface, underneath the warm air already prevailing over the water surface.

(2) The air temperature must be so low that a comparatively small amount of moisture will produce supersaturation, otherwise the heating which takes place during the lengthy saturation process will destroy the thermal stratification. In this connection it is worth noting that the weight of water per unit volume of saturated air at 10° C. is four times that at −10° C., and more than twenty times that at −30° C.

There are certain instances where these conditions are sufficiently satisfied so that dense fog is produced over warm water. But at best such fog can be only a transition phenomenon, persisting during the rapid transformation of the air mass properties, except as there is a continuous fresh supply of the cold air. In the Arctic regions, in the absence of strong winds, the normal condition both summer and winter is a very stable stratification of the lowest air layers, in summer by surface cooling, in winter by radiation, over the snow-covered surface. The opening of rifts in the ice over the Arctic seas may produce real fog locally. According to Professor Sverdrup there appears to be a correlation between the rather rare occurrence of real fog over the Arctic ice in very cold weather and the appearance of open spaces over the sea, but the complete darkness at that time of year makes reliable observation impossible. Certainly the marked occurrence of fog in cold weather at the edge of the solid ice cover and the open sea in the spring is often due to the spread of very cold air from the ice. The occurrence in winter of dense fog over open water in the Baltic Sea with a temperature of −10° C. or colder, is doubtless due to the spread of surface cooled air from the land. The same thing is observed over the Bay of Fundy, but over the open sea farther from shore it disappears. Another instance occurs in the northern Norwegian fjords in winter when the very cold air from the surrounding mountains, cooled by radiation, drains into the valleys. In all these cases there are cold air sources near the warm water surface which give rise to and maintain a marked surface inversion over the warm water surface. Over the open sea, far removed from cold land or ice, such a fog is impossible, for the development and maintenance of the inversion is impossible. Yet the possibility of the formation of ordinary sea fogs, such as those in the late spring

[28] Die Meteorologischen Bedingungen der Fernsicht, besonders der Alpensicht, im Südlichen Schwarzwald, Das Wetter, 42 Jahrgang, 1925; p. 122.

and early summer over the Newfoundland Banks, is frequently attributed to the presence of colder air over warm water.[29] Everything speaks against such a possibility. Sea fogs always occur over relatively cold water, and are most marked during the season when land surfaces are warm, and when the edge of the continuous Arctic ice is far to the north. At such times there is no possibility of the formation of a surface inversion in cold air over relatively warmer sea. And that fog formation can not take place in cold air over warm water without such an inversion is confirmed by the following theoretical and observational facts:

(1) The lower levels of the air mass are heated both by direct contact with the warm water surface and by the condensation of the vapor in the air mass. The cooling incident upon the evaporation of the moisture from the water takes place at the expense of the heat content of the warm water surface. Hence there occurs a transfer of heat from water surface to air layer by evaporation and condensation.

(2) The convective turbulance which is consequent on this heating of the lower air layers, in the absence of a surface inversion, rapidly conveys both heat and moisture upward, the effect being to establish an adiabatic or even superadiabatic gradient for saturated air. That this represents what actually occurs is shown by the characteristic properties of a P. A. mass advancing over a warmer sea surface. Such an air mass is *always* characterized by a steep vertical temperature gradient and cu. ni. convection, intense rain, hail, or snow *showers*, and extremely clear air below the cloud level, except as it is intermittently obscured by precipitation. Clearly the moisture from the warm sea is carried aloft and condensed there, not as a surface fog.

(3) There is not, so far as ascertainable, a single instance of an upper air observation of a sea fog without very stable stratification in the lower air. To justify the possiblity of a general fog formation in cold air over a warmer water surface without the existence of a surface inversion, it must be shown not only that the foggy air is colder than the water surface, but also that there is a rather steep temperature gradient prevailing at least to the top of the fog, for there must of necessity in the course of the fog formation have been some further heating of the air which is assumed originally to have been without inversion. It is quite possible to have ordinary sea fog over a sea surface which is slightly warmer than the foggy air, with a stable air mass stratification, for then it has either been formed over a colder water surface and brought by advection over the warmer water and not yet dissipated, or it has been produced by the cooling of the air mass by adiabatic expansion. This latter case occurs especially with marked cyclonic activity, and is considered later under prefrontal fogs.

2. *Autumn steam mists.*—Exactly the same conditions which give rise to Arctic sea smoke are the cause of the steaming visible over lakes and rivers in the early morning in clear autumn weather. In this case the air has been cooled over the land surfaces which cool by radiation so quickly, and has drained into the valleys, drifting over the much warmer water bodies. Exactly the same reasoning that holds against the formation of extensive or persistent low fog over a warm sea surface without the existence of a marked surface inversion holds against fog formation by this steaming process over extensive bodies of warm water on shore, and for the case when relatively cold air is brought over a warm, damp land surface. However, in the case of small bodies of warm water surrounded by higher land, the effect of the gravitational sinking of cold air in producing surface inversions over the warm water must be considered. The ground layer of air cooled by contact with the cold land surface may collect in a narrow valley or small lake basin with a degree of coldness and to such a depth that the formation of real steam fog becomes possible without destroying the inversion. The fact that the cold air is nearly saturated to begin with helps the process by decreasing the amount of steaming or evaporation which is necessary to produce fog. Actually such a fog is a radiation fog, for it is the contact of the air with the radiation cooled land surface which makes it possible, the warm water body simply supplying moisture. In other words, the fog is simply a radiation ground fog with this difference from the usual ground fog, that the moisture is supplied after the cooling by radiation occurs instead of before. As soon as the inequalities of land elevation are removed, or the water surface is so extensive that the cold air can not collect to an appreciable depth, the phenomenon becomes impossible, the warm water steam rapidly dissipating. Therefore there can not result a general fog formation in cold air over a warm damp *land* surface, any more than there can result a general sea fog over warmer water, because the formation of a surface inversion is equally impossible.

The actual fog dissipating effect of a warm water surface is shown by the often observed thinning of early morning radiation fogs over lakes and rivers, when there is no marked valley gravitational effect to counteract it. This principle is so well known to German commercial aviation pilots that it is a regular practice in the case of low radiation fog to shift the route so as to follow the course of a river. They frequently find it possible to come through in this manner when it is quite impossible over land. They remark that from above the fog the river course is always visible by the thinning of the fog over it, the result of convectional currents due to surface heating. At the same time visible steaming is taking place from the water surface.

The similar effect of a large inland lake has been statistically studied by Dr. E. Kleinschmidt,[30] at the Bodensee, in Germany. He finds that in autumn and winter, when the water surface is warmer than its surroundings, there is a marked increase of stratus and strato-cumulus formation above the lake, even to a distance of 20 kilometers inland. This is the result of the supply of heat and moisture to the air above the water; convection follows, and the condensation occurs in the higher levels. In autumn there is a very marked decrease in fog frequency in the vicinity of the lake. In winter there is some increase, which Kleinschmidt attributes to the supplying of moisture to the air, which is condensed over the surrounding cold land at a time when inland air is very poor in moisture content. In other words, the air is sufficiently cooled over the cold land so that the slight further evaporation necessary to saturate it can take place without sufficient warming to destroy the thermal stability. Earlier in the cold season the lake is still so warm that the thermal stability of the land-cooled air is rapidly destroyed. In spring and summer, when the water surface is colder than the land surface, so that cooling occurs over it, there is a marked decrease in low cloud in the lake region, but fog frequencies are from

[29] See for example G. I. Taylor, The Formation of Fog and Mists, p. 256.

[30] "Der Einfluss des Bodensees auf die Bewolkung und die Nebelbildung," Württembergischen Jahrbüchern für Statistik und Landeskunde, Jahrgang 1921/22. Sonderabdruck by Kohlhammer, Stuttgart, 1923. See also W. Peppler, "Lokale Stratusbildung am Bodensee," Beiträge zur Physik der freien Atmosphäre, XIII Band, 1926.

two to seven times what they are further inland. These results show conclusively that cooling and consequent thermal stratification over cold water produce fog and decrease cloud, while evaporation and heating over warm water produce convection and condensation aloft but can not of themselves produce surface fog. That requires a marked surface inversion, maintained by a steady cold air source, the product of radiation cooling.

II. RADIATION FOGS AND HAZE (CHARACTERIZED BY A MARKED INVERSION)

A. GROUND FOG (SURFACE INVERSION), GEORGII'S SENKUNGSNEBEL.

Ground fog is the low fog formed on clear almost calm nights, especially in the autumn. It is densest near the ground and diminishes in density with increasing elevation, never extending to very great elevations. It is characterized by an inversion whose base is at the ground and upper edge at the top of the fog, or if not a marked inversion, at least isothermalcy. It is evidently the product of the radiational cooling of a single night, usually dissipating in the course of the morning of the following day, and with its dissipation there disappears all trace of the ground inversion. It is, however, due to the readiness with which it is formed and its very general distribution, a considerable nuisance. It may form over any low or flat inland surface, on many clear, quiet nights, with sufficient density to render early morning aviation activity impossible.

It is in the vicinity of large cities that this type of fog appears in its worst form. The rôle played by hygroscopic nuclei in forming the very dense city fog of numerous small particles with less than saturation humidity has been discussed in the first part of this paper. The result is that even a ground fog can assume proportions in a city such as London that are impossible elsewhere. It may even persist from day to day, growing denser and thicker every night, until it is cleared away by wind. Even the densest London fogs are often of this local ground type, as shown by observations from surrounding stations, and not of the more extensive high inversion type, which are so characteristic of the continent in late fall and winter.

The physical processes effecting the cooling of the lower air layers and the resulting condensation forms are doubtless rather complicated. W. Georgii explains this type of fog very simply, by assuming that condensation takes place on the larger dust particles which begin to settle in the afternoon, as soon as the convective activity instigated by the sun's action during the day has ceased. The lower air levels cool by radiation from the earth's surface and become damp, the dust particles settle down into this layer, and condensation begins on them, the resulting fog being thickest near the ground, where the cooling is greatest and the most dust particles are assembled. It is from the sinking of the dust nuclei that he gets his name "Senkungsnebel." As concluding evidence of his theory he remarks that when visible layers of smoke and dust haze were evident in the late afternoon of a clear day, fog formation almost always followed during the night. Against this theory it may be remarked that all the evidence points to the fact that it is not the large dust particles that act as nuclei. The correlation between fog occurrence and afternoon dust or smoke haze may be attributed to the fact that where there is visible smoke there are also probably hygroscopic nuclei, but with more reason to the meteorological consideration that dust and smoke haze are the result of prevailing light winds and a stable stratification, which are essential conditions for the formation of ground fog. In other words, the fog and haze are both the result of certain meteorological conditions, and neither one to any extent the cause of the other. Before attempting an explanation of the formation of ground fog, certain theoretical and observational facts about the factors involved will be considered.

G. I. Taylor in a theoretical consideration[31] of the rôle played by direct conduction of heat from air mass to ground surface, and the molecular diffusion of water vapor, in an air layer perfectly at rest over a ground surface cooling by radiation, came to the following conclusions:

(1) The greatest possible vertical extent of the effect of conductive cooling in the course of one night is about 4 feet.

(2) The molecular diffusion of water vapor downward can take place at about the same rate as cooling by conduction upward. In other words, in the course of one night dew can be deposited in calm air from a layer extending only to 4 feet above the ground.

(3) Since in the formation of ground fog cooling spreads upward from the cold surface to much greater heights than 4 feet, the effective cooling factor must be dynamic turbulence, not conductive cooling.

The correctness of Taylor's calculated effect of cooling by conduction to the ground is demonstrated by Hellman's observations at Potsdam,[32] taken over a level grass surface during perfectly clear nights in August and September, 1916. The successive average differences of minimum temperatures at 5, 10, 15 (etc.) to 50 centimeters above the ground are as follows: 0.80°, 0.44°, 0.33°, 0.24°, 0.16°, 0.09°, 0.05°, 0.03°, the average difference between 5 and 50 centimeters elevation being 2.7° C. for 14 nights, the regularity such that the extreme values were 2.3° C., and 3.1° C. Such regularity indicates perfectly calm air on all occasions near the ground.

Taylor's calculations take no account of the cooling of the air by direct radiation into space.

A. Defant has considered especially the working of this factor in the lower air strata both observationally and theoretically.[33] His principal results may be summarized as follows:

(1) From the analysis of humidity and thermograph records over a 10-year period at Kremsmünster and Tiflis on clear calm nights, he found that the air cooling during the night varies directly as $T_a - T_s$, where T_a and T_s are air and ground surface temperatures. But $T_a - T_s$ varies inversely as the moisture content of the air. Hence the air is cooled primarily from the ground, and this cooling is hindered by a large moisture content simply because the ground cooling is hindered, by the well-known blanket or greenhouse effect of atmospheric moisture. But Defant found by a similar analysis on Sonnblick (3,105 meters), where the nightly cooling is much less than at low levels, that this cooling is directly proportional to the mositure content of the air, hence that cooling by direct radiation from the air is the principal factor. These results are all in accord with Emden's assumption that the cooling of air by radiation is directly proportional to its vapor content. (2) Defant's theoretical considerations (based on Emden's radiation theory) indicate that

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[31] Loc. cit. The Formation of Fog and Mists, p. 261.

[32] Über die nächtliche Abkühlung der bodennahen Luftschicht, Sitzungsberichte der königlichen Preussischen Akademie der Wissenschaften, No. XXXVIII, 1918.

[33] *a.* Die nächtliche Abkühlung der unteren Luftschichten und der Erdoberfläche in Abhangigkeit vom Wasserdampfgehalt der Atmosphäre, Met. Z., 1918.

b. Über die nächtliche Abkühlung der untersten Staubbeladenen Luftschichten, und Die nächtliche Abkühlung der untersten Luftschichten bei bewegter Luft, Annalen der Hydrographie und Maritimen Meteorologie, 1919, Vol. XXXVII.

dust may play the same rôle as water vapor in effecting cooling of the air by radiation. Furthermore, the sinking of cooled dust particles in numerous small cold air envelopes may materially increase the vertical "Austausch," or turbulence effects, in the case of stable stratification. (3) The effect of wind (from 10 years records at Kremsmünster) is *always* toward a relative warming of the lower air strata. Defant finds that already at force 3 Beaufort no further warming can be noted, or that all local effect of ground cooling is effaced. In this connection it is interesting to note that Taylor finds that of the 70 instances at Kew Observatory between 1900 and 1905 of fog formation during the night., in 62 cases was the wind force at midnight less than 1½ m/s, in 5 cases between 1½ and 2½ m/s, and in 3 cases between 2½ and 4 m/s. Thus a wind force greater than the lower limits of 2 Beaufort even at midnight is enough to prevent fog formation before morning.

In the light of these various facts, the following seems the most probable explanation of the process of ground fog formation. Let there be assumed clear sky, so that the radiation process is unhindered, and the presence of an air mass of moderate moisture content and stable stratification, which permits of very light movement and small dynamic turbulence in the lower levels. If there is absolute calm the mass will cool throughout by radiation of vapor or dust content, perhaps 2° to 3° C. Unless the mass was very moist to begin with, the amount of this cooling will not be sufficient in one night to produce fog formation. The layers directly over the ground, up to 3 or 4 feet, will cool further by conduction to the ground which has become colder by radiation, an amount which is greater the drier the air mass throughout. This cooling may be more than 4° C., as Hellman's observations show, directly at the surface. The result is supersaturation of the lowest foot or even meter of the air, which is dissipated by the formation of heavy dew on the cold grass through the molecular diffusion downwards of the vapor. Thus over a level landscape, with complete calm, there is only heavy dew formed unless the air was very damp originally, or extremely hygroscopic nuclei are present.

If, however, the land surface is uneven, the gravitational effect collects the heavy air previously cooled probably to saturation by conduction to the ground, in low lying places to considerable depths. A very slight further cooling of this air by direct radiation to space effects supersaturation. Taylor's calculations show that this can not be dissipated by molecular diffusion, hence fog formation occurs in low lying sections in complete calm.

Finally, consider the effect of dynamic turbulence. As soon as there is the slightest air movement, the dynamic turbulence prevents the formation of a marked ground inversion, the cooling effect being distributed more rapidly upward. If the velocities are light (2 m/s), the dispersing effect is not rapid enough to efface the ground cooling, but rather makes its influence felt throughout the lower layers, instead of only the ground layer. In this case a much greater mass of air is cooled by the ground effect and often saturated. Since the saturation can not be dissipated by dew, this is the condition most favorable for general ground fog formation. As soon as the air movement becomes a very little increased, the dispersion of the ground cooling, hence relative warming of the lower air, becomes such that fog formation is out of the question. Ground inversions can no longer occur. But even when there is such turbulence that saturation of the lower air is impossible by cooling, the ground surface may by radiation fall below the saturation temperature of the air, in which case light dew will be deposited.

In general, high humidity in the cooling air mass is favorable to the formation of ground fog, in spite of the fact that it decreases the radiational cooling of the ground surface. This effect is more than outweighed by the increased direct radiational cooling of the air to space and by the increase of the saturation temperature in the air. Dampness of the ground surface seems also to be favorable. Probably it increases the radiation from the surface, and until the ground has cooled below the saturation temperature of the air, it results in greater evaporation to the air and so increasing humidity.

The rôle played by relatively warm-water bodies in supplying moisture to the cooled air to facilitate fog formation under favorable circumstances, as well as the usual fog-dissipating effects of such warm-water surfaces, have been considered in detail under autumn steam mists, above.

Since clear skies are essential to the formation of ground fogs, they occur in anticyclonic situations. Furthermore, since they require stable stratification and light winds, they occur only in C. Trans. A. masses; in other words, in anticyclones that have aged and become thermally stable. In the first outbreak of a P. A. mass they are conspicuously missing, for the characteristic fresh winds and relative instability of such a mass result in a degree of turbulence which makes ground inversions quite impossible.

B. HIGH FOG (UPPER INVERSION) GEORGII'S STRAHLUNGSNEBEL

This type of fog is especially frequent over western continental Europe, wherefore the following discussion of the typical phenomenon applies to that locality. Certain more general considerations follow the discussion of the conditions and causes of its formation.

High fog is characterized by a marked inversion above the ground (from 200 to 2,000 meters), just as ground fog is characterized by a surface inversion. The greatest density of the fog is at the base of the inversion, as the greatest density of ground fog is at the ground. High fog may extend from the ground all the way up to the inversion, with increasing density, or it may be quite clear of the ground, appearing simply as a dense, low stratus, almost without motion. Like ground fog it is characteristic of anticyclonic situations, usually very large and stagnant anticyclones. It is less local than ground fog, extending uniformly over extensive regions, and much more persistent, sometimes enduring for weeks. The high fog inversion persists day and night, even though the fog may sometimes dissolve by day, whereas the ground fog inversion is usually the radiation effect of a single night, never persisting through the day except as the fog itself is rendered extremely stable by a dense pollution of the atmosphere with hygroscopic nuclei.

The very marked characteristics of high fog are best shown by a brief consideration of a good example. A very excellent case is one treated by W. Peppler,[34] which occurred over all Germany from November 15 to December 6, 1921, covering all the lowlands with fog and low stratus, from which the highest Mittelgebirge stations protruded. Statistical averages for the entire 21-day period for 19 stations ranging from the lowest plain elevations (Mannheim 100 meters) to the mountain tops (Hochenschwand 1,005 meters, Feldberg 1,270 meters)

[34] Ein Beitrag zur Kenntnis des Nebels, besonders in Südwestdeutschland, Das Wetter, 41 Jahrgang, 1924, pp. 173–176.

showed the following situation: (1) An average temperature of −2° C. in the plain, decreasing to −4.7° at about 700 meters, and increasing at least up to Feldberg (1,270 meters), which had 0° C.; (2) average relative humidities increasing from 80 per cent in the plain to 97 per cent at 700 meters and decreasing to 61 per cent at 1,270 meters; (3) average cloudiness of from 50 to 90 per cent up to 450 meters, decreasing to 28 per cent at 1,270 meters, and a total duration of sunshine ranging from 9.2 hours at one valley station up to 152 hours at Feldberg. These are 21-day averages that do not show either the conditions at the top of the inversion or the abruptness of the inversion. But they show clearly the persistence of a low cold and damp air layer, with a large inversion above, the average elevation of whose base was 700 meters and top above 1,000 meters. Over northern Germany the same contrast existed between the Brocken (1,153 meters) and the lowland stations (Potsdam, Magdeburg, etc.).[35] On the Brocken, from November 23 to December 1, the average temperature was 1.7° C.; humidity, 19 per cent; cloudiness, 6 per cent. In the lowlands the average temperature was about −5° C.; humidity, 85 to 90 per cent; persistent fog and cloudiness, 50 to 100 per cent. During the entire period the situation was anticyclonic, a stagnant anticyclone of great magnitude being central over southern Russia, the winds light southeast. Such striking situations are so frequent over Germany that they have been much studied and a great amount of observational material gathered showing surface and upper air conditions.[36] In individual cases the temperature inversion may exceed 15° C.

Evidently the first step in the explanation of high fog is the explanation of the temperature inversion. It may be possible, as Georgii maintains, that a ground fog can pass over into a high fog as a result of marked radiational cooling of an air layer above the ground, due to great dust or vapor content of the radiating layer. Georgii thinks he has aerological data showing such a development in a few cases. But at any rate such a formation must of necessity be rather local. That the usual extensive anticyclonic developments of inversions accompanied by high fog are not the result, but rather the cause of the fog formation is shown by the fact, which Georgii points out with excellent illustrations from German aerological data, that the inversion usually exists long before the fog appears. It may be gradually intensified for some time after the fog formation appears, however. These very marked temperature inversions, as Georgii and many others have pointed out, are the surfaces of subsidence in aging anticyclones. Consider the case of an extensive outbreak of P. A. in winter. Such a mass leaves the arctic regions as a strong outflow, very cold at all levels. It flows southward with decreasing movement. If it has advanced by an inland route over Russia and the Baltic, it usually becomes quite stagnant over southwestern Russia, or if its path was further to the west, over the Norwegian Sea and Scandinavia, it may become stagnant over western Europe (Germany and Poland). Such a stagnant mass of cold air, by its greater density, constitutes an anticyclone. But it also represents a very great amount of potential energy, which even before stagnation is complete begins to be transformed into kinetic energy and heat energy by the settling of the air mass. The gradual settling of this mass, with its horizontal outspreading, establishes an anticyclonic circulation which in turn leads to a dynamic compression of the mass and growth of pressure at the center. Thus the anticyclone becomes of vast extent, rather symmetrical and very high pressure in the center. The upper portions of the air mass are warmed by both dynamic and adiabatic compression. The lower levels, near the earth, remain rather stationary. The net effect is a flattening out of the mass, a crowding of the surfaces of equipotential temperature,[37] hence the development of an inversion at the level where the stationary lower air layer passes over into the spreading and settling portion of the mass. Such an inversion surface as shown by Georgii's excellent data has its maximum elevation at the center of the anticyclone, and slopes away slightly toward the outer edges.

This explains the temperature inversion but by no means explains the fog. That is dependent in part upon the history of the air mass. When its route has been over land, over the Baltic to southwestern Russia, the lower layers are rather dry and cold from the very first. But in spite of their original coldness, these lowest air layers cool still further after their arrival over continental Europe, at the same time that the upper layers become much warmer. Probably this cooling is due to radiation from the ground, favored by the unusually dry and clear condition of the upper air. No ground inversion forms, because there is enough air movement so that the turbulence carries the cooling effect upward to the big inversion. Also this inversion surface, with the great decrease in dust content and presumably appreciable decrease in absolute humidity that take place here, must be an active radiating surface,[38] in which case there will be a tendency for the inversion gradually to increase in magnitude, and for the maintenance of an appreciable temperature gradient up to the inversion. Both conditions are indicated by aerological observations.

The great smoke and dust content which is so prevalent below the large anticyclonic inversions comes from the industrial regions, gathering in density for many days, due to light winds, to the lack of precipitation, and to the impossibility of convection above the inversion level. When not marked by fog, such an aging anticyclone is always marked by dense smoke haze with a boundary in the inversion layer. This indicates also the presence of many hygroscopic nuclei, which spread under these favoring conditions far from the sources of pollution. In an air mass of this origin, fog formation is usually marked only in the southern and western part of the anticyclone, where there is usually a light flow from the south or southeast. It is thus where the inversion layer is lower than in the center, and where the air has drifted farthest from the source, cooled by ground and dust radiation, and thoroughly permeated with smoke and hygroscopic pollutions. Probably these factors all work to effect fog formation. In one instance, the last week of February, 1928, southerly air of this type, which had been too dry over the continent to form fog, drifted up along the coast of Norway, acquiring enough moisture from the sea to give two days of dense fog, at the same time that the inversion persisted. Needless to say, such a formation could not occur if the air was much colder than the

[35] See G. Grobe, Witterungsanomalie auf dem Brocken im Nov. und Dez. 1921, and R. Süring, Auffallende Trockenheit auf dem Brocken im Nov. und Dez. 1921, Met. Z. 1922, pp. 152–154.

[36] See W. Georgii, Ursachen der Nebelbildung, 1920: W. Peppler, Ein Beitrag zur Kenntnis der Nebelbildung, 1924; and G. Hellman, Der Nebel in Deutschland, Sitzungsberichte der Preussischen Akademie der Wissenschaften, 1921, No. LII. Especially has W. Peppler found for 112 cases of kite ascents at Friedrichshaften in high fog an average temperature inversion of 6.8° C., an average humidity decrease in the inversion from 100 to 49 per cent.

[37] For a detailed theoretical consideration of the kinematics of the genesis of fronts and of level inversions, see Bergeron, Wetteranalyse, pp. 73–84.

[38] Where the cumulative effect of radiation over a period of days is to be considered, it must be remembered that active radiating matter is also active absorbing matter. But in the latitudes under consideration here, during the cold season, the number of hours of sunshine each day is less than half the number that the sun is below the horizon.

sea, nor could it occur without hygroscopic nuclei. In this case, at its source over Germany, dense smoke haze had persisted for a week, with an inversion of between 5° C. and 10° C. at only a few hundred meters. At the same time the surface air was only about 0° C.

When the anticyclonic development occurs in a cold-air outbreak which has passed directly south over the sea the worst cases of high fog occur. Then the mass comes on land somewhat warmed and nearly saturated in the lower layers. As the stagnation, settling, and inversion development take place the lower layers cool by radiation, aided by their vapor content, to such a point that general condensation soon occurs. Fog and dense stratus form up to the inversion, even at its highest point, which may be over 2 kilometers at the center of the anticyclone over Germany or Poland. The condensation frequently goes so far as to give light precipitation in the form of snow or sometimes ice crystals (needles). It is not infrequent in central Europe to have for days in winter a prevailing pressure of more than 780 millimeters with thick stratus, fog, light precipitation, and intense cold.

The very stable anticyclonic developments over Europe occur only after a very marked cold-air outbreak from the north. There very frequently occur, however, more transitory inundations of the continent by M. P. A. or M. Trans. A. masses from between NW. and SW, which do not stagnate over the continent sufficiently to give either marked anticyclonic or marked inversion development, yet are very productive of fog. This is type III in the outline, which is treated below.

For the development of real anticyclonic fog, there are evidently two fundamental favoring conditions:

(1) Stagnation of the developing anticyclone over a cold continent.

(2) A previous maritime life history of the stagnating air mass.

From this it follows that continental Europe is the quite favorable ground for such fogs, as is observed to be the case. It also follows that they do not develope over the sea, where surface warming is too great and stagnant anticyclonic development impossible. Nor do they develop over the British Isles, even though the inversions from the continental anticyclones often extend over England, as shown by aerological observations at Duxford and Farnborough. Over North America the real high fog is practically unknown. The reasons for the contrast between Europe and North America in this respect at once become evident on a consideration of the two essential conditions mentioned above.

In the first place, all the cold-air outbreaks in North America which result in anticyclonic development move southward from Alaska or northern Canada. Such an air mass starts cold and dry from a winter Arctic anticyclone and remains so as it moves southward over the cold continent. At no point does its path lie over the open sea, hence it has no opportunity to acquire the moisture in the lower layers which was shown to be so important. The high mountains along the west coast of North America effectually shut out all inflow of air masses of maritime characteristics. What little may find its way over the mountains is thoroughly dried in the process. All northern Europe, on the other hand, apart from the Scandinavian Peninsula, lies open to direct invasion by maritime air masses over the lowlands, which renders the climate so characteristically maritime.

In their dryness the anticyclonic developments in North America resemble those in Europe where the air mass has moved southward over the most easterly route. But in America the stagnation is never so marked as in Europe. The gradual spreading, radiation cooling, and permeation by smoke, hygroscopic impurities, and a certain amount of moisture of the subinversion air layer may continue for weeks in the European anticyclonic development until an air mass originally of the driest may become marked by considerable fog formation. This is impossible over North America. The circulation is too rapid and the succession of vigorous cyclones too close to permit of the stagnation of extensive winter anticyclones. This comparatively vigorous circulation and close succession of young and growing cyclones from central North America northeastward and eastward over Newfoundland and the North Atlantic is the consequence of the steep poleward temperature gradient in this region, which is in turn the result of the general atmospheric circulation and the surface currents in the North Atlantic. According to Bergeron's [39] terminology, it is a region of "frontogenesis," of front formation, and hence of cyclogenesis. The region north of western Europe eastward over the interior of Russia is, on the other hand, a region of slight latitudinal termperature gradient, of "frontolysis," or dissipation of fronts, and hence of stagnating circulation and filling cyclones. This makes possible the frequent extensive stationary anticyclones over northern Europe.

C. INVERSION HAZE

Inversion haze, like the radiation fogs which develop in connection with inversions, are of two kinds, *ground haze*, and *high haze*, according as the inversion is a ground inversion or a high inversion. The source of this haze is the smoke and dust of large cities. Hence it is characteristic of industrial regions. Inversions are, in such regions, invariably accompanied by a certain amount of smoke haze, which always renders visible the stratified condition of the atmosphere when not obscured by fog. Ground haze is of much less importance than ground fog. In the first place it is so much less dense that its limited vertical extent does not permit of its being seriously obscurative of visibility. Like ground fog, its density is greatest close to the ground, decreasing rapidly with elevation. In the second place, due to the almost complete calm which characterizes a ground inversion, it is of necessity extremely local. It can form only in the immediate vicinity of the polluting source, whereas ground fog can form over wide areas. Finally, being, like ground fog, the product of a single night, dissipating with the dissipation of the inversion, it can not represent the accumulation of a very great amount of obscuring matter. Its formation is simply due to the absence during the night of convection or advection currents to remove the smoke pollution.

High haze is of much more importance both practically and theoretically than ground haze. The most characteristic thing about high haze is its stratification in distinctly individual and homogeneous layers of the atmosphere. A. Wigand in his numerous balloon ascents has observed that haze strata are of two types, [40] namely, (1) in the higher levels, strata of relatively cold and humid air, due to the presence of water droplets large enough and numerous enough to cause a hazing effect; such

[39] For Bergeron's treatment of the dynamics of frontogenesis and frontolysis and a schematic representation of how these processes take place in the general circulation of the northern hemisphere, see Wetteranalyse, pp. 84–94, and figures.

[40] Die vertikale Verteilung der Kondensationskerne in der freien Atmosphäre, Annalen der Physik, Band 59, 1919.

a water haze is simply the first stage of an a. st. or ci. st. formation, and is not considered further here; (2) the dry smoke and dust haze layers which are coincident with anticyclonic inversion layers and which have their greatest density in the upper portion of the inversion layer. Such is the haze which is under consideration.

This high inversion haze is practically coextensive with the anticyclonic inversion, but its density is greatly intensified over large industrial cities wherever smoke pollution is abundant. That the hazing impurities result entirely from this type of pollution follows necessarily from the original clearness of the anticyclonic air mass, the very light prevailing wind velocities during the development of the haze, and the moist and frequently snow-covered condition of northern continental surfaces in winter. The observed distribution of the haze is further proof of its origin. In the immediate vicinity of the source of pollution the haze extends from the ground to the inversion layer, where its density is greatest. Further removed from the source it is most marked in the inversion layer, having both an upper and a lower boundary. In the vicinity of the source of pollution the density of inversion smoke haze is directly proportional to the amount of the inversion and inversely to the wind velocity. Further from the source the principal factor is the direction of the wind relative to the source. Such haze may persist for weeks, as long as the inversion does. It is the result of the continued collection in the inversion of smoke pollution, and it may become so marked over a wide area as to render visibility below the inversion poor over a considerable part of western Europe. Over the large cities, if the winds are very light, it may become so dense as to render the ground completely invisible to one above the inversion. Evidently it is primarily a winter phenomenon, for the great anticyclonic developments are a winter phenomenon. In summer the continental heating attendant on clear skies does not permit of the marked persistent high inversion formations, but ground inversions and ground haze, the result of a single night's cooling, may occur in summer. The fact that objects above the haze may be quite distinctly visible to one on the ground, while at the same time the ground is entirely invisible to the observer above the haze, has long been known to aviators. This obscuring tendency of a haze layer for everything below it is the result of its efficacy as a reflecting surface. To the observer above such a large part of the light coming to him from below is sunlight reflected directly from the haze layer that the relatively weakly lighted ground objects are quite lost to perception. But to the observer below the only light coming to him from a point above, except for the relatively small amount of haze-scattered sunlight, is the unreflected and unscattered portion of the direct rays from relatively strongly lighted objects above the haze.

The outstanding characteristic of high inversion haze in contrast to high fog is the fact that whereas the fog reaches its greatest density at the base of the inversion, decreasing rapidly above to zero, the haze layer, when far enough from the source to have a distinct upper and lower boundary, reaches its greatest density near the top of the inversion, falling off very rapidly above.

Both Georgii, and to a certain extent A. Wigand, would explain this vertical distribution of smoke or dust in terms of the density of the air. Assuming that the particles have formerly been carried aloft in regions of active convection and are everywhere in stable anticyclonic regions slowly settling, they will at a marked inversion come into a region of denser air, and will in consequence of their slower fall velocity in the dense air collect to a greater density at the inversion. But that such an effect must be totally inadequate, quantitatively, to account for haze layers is at once apparent. Wigand has shown that in such a layer the kern count is often several times what it is a short distance above. Presumably, from the obscurity of visibility the concentration of dust and smoke particles must be even greater. Suppose there exists a temperature inversion of the large value of 10° C. This will effect an increase in air density of 4 per cent. Whatever the nature of the particles, it is out of the question that a 4 per cent increase in air density should greatly affect their fall velocity, whereas this velocity must be reduced by 75 per cent at least to effect the observed concentration of particles.

The explanation is rather to be found in an examination of turbulence and wind velocities. As shown by extensive aerological data (see Georgii, W. Peppler, etc.), the usual conditions of temperature gradient and wind prevailing up to and through an anticyclonic subsidence inversion are: (1) Very light winds and moderate lapse rate (average 0.6° C. per 100 meters) up to the base of the inversion; (2) considerable temperature and wind velocity increasing throughout the inversion layer, and frequently a very marked change in wind direction (tendency from E. to SW.); and (3) above the inversion a moderate temperature lapse rate, and a very steady wind, completely undisturbed by convection from below.

Thus in the lowest layer the smoke pollution works readily upward by the slight turbulence produced by light wind flow over uneven surface, and by a moderate temperature gradient. The actual inversion layer is very productive of mechanical turbulence, in spite of its very stable stratification, due to the usual rapid change of wind velocity and direction with elevation. The upper layer, on the other hand, as a result of its very regular air flow and moderate stability, is but very slightly productive of turbulence, and relative to the layer below is highly destructive of it.[41] Therefore the turbulent activity of the inversion layer falls off very rapidly with elevation in its upper portion (see Rossby's curves), and at a short distance above, in the upper layer, the low turbulent activity characteristic of that layer is reached. The region where the turbulence decreases most rapidly, in the upper portion of the inversion layer, is where the smoke and dust collect. The greater wind velocities prevalent here spread this smoke horizontally comparatively rapidly. From this follows the widespread prevalence of the high inversion haze, even far removed from the sources of pollution. This process is often quite visible on a clear calm morning when an upper inversion exists. A column of smoke from a factory chimney may be seen often to rise straight up for some hundreds of meters. Then it reaches a level where it begins to diffuse rapidly by spreading out horizontally (the inversion layer). At the top of this layer it drifts off rapidly in a definite direction, without diffusing further upward, appearing as a thin haze layer.

High inversion haze, unlike the fog, is quite common in the eastern United States, for there occur both the anticyclonic inversions and the large industrial cities. However, it does not acquire the density over a wide region that it does in Europe, due to the more rapid general circulation.

Two kinds of dry haze have been considered—the tropical haze, which is simply the remains of fine dust blown up by the wind and occurs only in tropical air,

[41] For a theoretical treatment of the distribution of turbulence in the atmosphere see C. G. Rossby, The Vertical Distribution of Atmospheric Eddy Energy, the MONTHLY WEATHER REVIEW, August, 1926.

and inversion smoke haze, the result of industrial pollution, which occurs only in continental polar air. Except for occasional forest-fire smoke or volcanic dust, which may occur occasionally in any kind of air mass, these are the only types of dry haze which are of any practical importance.

III. MARITIME FOG—CHARACTERISTIC OF M. TRANS. A. MASSES WHEN COOLED OVER LAND

The formation of this type of fog is dependent on the cooling over land of fresh M. P. A., or the further cooling of an M. P. A. mass in which the transformation to M. Trans. A. has already begun. This latter case is the one where the M. P. A. mass in the course of a long sea journey has already been further to the south, and comes over western Europe from the southwest, slightly cooled and therefore stable in the very lowest layers. In either case, the air mass at once suffers further cooling in its lower levels, furthering its transformation from polar to transitional character. It is due to the maritime origin of the air masses in which it occurs that this fog is called maritime fog. But its actual formation invariably occurs over land, not over the sea.

In the formation of this fog, advection plays an important rôle. At the same time, the principal cooling seems to take place by radiation. But it is quite distinct from the radiation types treated above. Those types follow direct northerly outbreaks of P. A. after lengthy stagnation and anticyclonic development with marked upper air subsidence and inversion. Transition fog accompanies inundations of western Europe by M. P. A. from between the NW. and SW. Such outbreaks are usually characterized by their transitory nature, occurring between successive cyclones when the general eastward circulation is active instead of stagnant. There is therefore no stagnating anticyclonic development, no formation of subsidence inversions, and no upper layer of warm dry air. Everything is too transitory for such marked developments. The fog is generally formed within 24 hours of the passage inland of the M. P. A. mass, usually long before the appearance of any inversion. If an inversion appears after a time, it is due to the cooling of the lower layers and not to the adiabatic heating of the upper layers. That such fog is extremely common, as Calwagen had remarked, follows from the extreme frequency of the invasion of western Europe by such M. P. A. masses and from certain characteristics of these masses to be considered in the explanation of the fog.

The usual weather conditions that accompany such an inflow of old M. P. A. may be of the most nondescript nature, not the settled conditions that accompany inversion fog. Usually there are at least remnants, at first, of the shower activity that characterizes fresh M. P. A. masses. Furthermore, there may be remnants of old occluded fronts or secondary cold fronts. There is also frequently a certain amount of orographical influence evident in the very saturated lower levels. The general result, at least at the beginning of such an inflow, is considerable cloudiness and often light intermittent rain or orographical drizzle. The fog formation frequently begins under such nondescript conditions, often with some wind prevailing.

The one outstanding characteristic of all such inflows of M. P. A. or incipient M. Trans. A. over western Europe is the very marked cooling which at once takes place as the air mass moves inland. No doubt this effect is the primary cause of the frequent dense fog formation which occurs in such air masses. Quite frequently within 24 hours of the time that the air mass leaves the sea, the temperatures over the lowlands show a decrease of as much as 5° or 6° C. in the lower levels of the mass, even with an overcast sky. At the same time the high level stations show no corresponding cooling. The result is a very quick development of a stable gradient, possibly even slight inversions, and very often a dense fog to some elevation.

The contrast in the case of an inflow of T. A. is striking. M. P. A. and T. A. may both invade Europe from the SW., with quite similar surface layer temperatures, humidities, and winds. But the T. A. current, as it moves inland, suffers only a very gradual surface layer cooling usually with the characteristic drizzle and sometimes rather thin fog. The M. P. A., on the other hand, suffers immediate marked surface layer cooling and very often dense fog formation. What is the cause of this difference?

The difference in the upper air conditions of the typical M. P. A. mass and the typical T. A. mass as it first comes on shore is excellently shown by the upper air records obtained by C. K. M. Douglas at Berck (near Bologne) in 1918 and 1919. From a comparison of the records of 6 plane ascents selected by Douglas [42] as "drizzle situations" (T. A. mass) and 15 ascents selected as "shower situations" (M. P. A. mass), it is found that the average vertical decrease in temperature through the first 3 kilometers in the 15 M. P. A. ascents is 9.1° C. greater than in the 6 T. A. ascents. Apparently, then, an M. P. A. mass coming off the sea with the same temperature and near saturation humidity as the T. A. mass in the lowest layer will at only 3 kilometers be 9° C. colder. The stratified T. A. mass represents the more normal condition of the atmosphere; the equilibrium state which is gradually established in undisturbed situations. The unstable M. P. A. mass represents an abnormal condition which is only maintained by the constant supply of heat and moisture to the lower layers from the warm sea surface. As soon as the air mass moves inland this constant heat supply ceases. At once the forces acting to produce the normal undisturbed equilibrium condition make themselves felt, effecting a marked surface cooling and fog formation and probably some warming of the upper layers. Just what the process effecting the modification is it is not easy to say. Probably the very high absolute humidity of the lowest warm and saturated layers render the radiation factor of great importance. It may be radiation equilibrium which is established. But undoubtedly as long as the steep temperature gradient prevails, and there is an appreciable wind velocity, turbulence plays an important part in the upward diffusion of heat.

The nature of the local upper air changes which take place at a fixed point in the course of a typical development of high inversion, maritime, or T. A. fog appears very clearly in the monthly charts prepared at Lindenberg, near Berlin, showing the variation in the height of the potential isothermal surfaces over Lindenberg during the entire month. The heights of the equi-potential temperature surfaces at Lindenberg are plotted as ordinates, the time as abscissae, and values of the ordinates interpolated between successive observations to

[42] Selected at Bergeron's request simply as typical drizzle and typical shower situations. Bergeron uses them as the most reliable observations obtainable to show the characteristic upper air properties of P. A. masses and T. A. masses with the continental influence at a minimum. See Wetteranalyse, p. 45.

give the continuous course of each surface over Lindenberg throughout the month. The observational material is rather complete, consisting of at least two kite or captive balloon ascents daily at Lindenberg, an occasional sounding balloon, and a daily plane ascent in Berlin (at Tempelhof). Noteworthy meteorological conditions, as fog, cloud forms, forms of precipitation, and vertical air movements, are also entered on the chart by time of occurrence, to give a complete continuous picture of thermal stratification and atmospheric and meteorological activity at the station throughout the month. In the case of high inversion fog there appears first a great lifting of the isothermal surfaces extending to at least 5 or 6 kilometers, the cold air invasion, followed by a rapid sinking again in the upper levels (adiabatic heating by compression), while in the ground layers the isothermal surfaces retain their level (cold surface layer). The result is a great crowding of the surfaces between 1 and 2 kilometers (the inversion—frequently a potential temperature increase between these levels of 18° C.). This condition usually remains for many days, the crowded isothermal surfaces running evenly horizontal, while continuous fog is often indicated below them, clear skies and descending air motion above. The maritime fog occurrences are much less striking. There first appears a raising of the iso-potential temperature surfaces between 1 and 3 kilometers (often the establishment here of a mean temperature gradient of 0.8° C. per 100 meters) followed by an appreciable raising of the lower surfaces (surface cooling), but rarely does there appear a vertical increase of potential temperature of as much as 8° C. per kilometer. The fog frequently makes its appearance almost as soon as the lower layer cooling begins. In the case of a T. A. invasion the chart shows a great descent of the potential temperature surfaces at all levels up to at least 5 or 6 kilometers, and ascending air motion at decreasing levels (approaching warm front). Fog is not usually indicated here, but is occasionally. If it occurs before the zone of most rapid temperature increase, it is prefrontal fog (considered below). If in this zone, or afterwards, it is T. A. fog.

Maritime fog formation takes place so rapidly when M. P. A. or M. Trans. A. comes from a warm water surface to a land surface in winter that even over the British Isles it is a frequent type of fog. In the United States, however, it is almost completely missing. This is primarily due to the effective shutting out of the air masses favorable for its development by the high mountains along the western coast of North America. Probably it occurs frequently in autumn and winter over the more inland region of the Pacific coast. The fact that stations located here (Seattle, Roseburg, Red Bluff, Sacramento, and Fresno) show their greatest fog frequencies from October to January [43] seems to verify such an assumption. The more exposed stations (Tatoosh Island, San Luis Obispo, and Los Angeles) show a marked summer maximum between June and August, which is due to monsoon fog. San Francisco and Fresno run high the whole year except in the spring. The more inland stations in the North Atlantic States east of the Appalachians also show a winter maximum which may be due to this type of fog, but the coldness of the waters off the coast in this region and the relative infrequency of invasion of this coast by maritime air of polar origin render such a fog formation infrequent. The fog frequencies at such stations are small, as Köppen's figures show.

The consideration of maritime fog completes the discussion of air mass fogs. These are the fogs whose persistency and frequency are such as to make their influence evident in climatological means. Monsoon fog and sea fog over the relatively cold seas in summer, inversion fog and maritime fog over the relatively cold land in winter, these affect the statistical averages. They represent surface cooling of warm air from the continents in summer, and surface cooling of the damp air from the seas in winter. For this reason Köppen's statistics lead him to the conclusion that fog is essentially a coastal phenomenon, occurring over the colder seas in summer, the colder continents in winter. For the same reason land fog frequencies are generally greatest in the early morning, least in the late afternoon, while the frequencies of fogs formed over the sea are frequently reversed.

The fact that fog represents fundamentally cooling from below, thermal stratification, and low level condensation, while cloud represents fundamentally heating from below, unstable stratification, and high level condensation, results in an average seasonal and daily variation of visibilities just the reverse of the condensation processes. A. Peppler, from numerous visibility measurements of his own at low and at high elevations, as well as from a statistical analysis of numerous other visibility data from nearly all parts of Europe and over the North Sea, has come to the following general conclusions: [44]

(1) Over continental Europe at low elevations horizontal visibilities are best in summer and poorest in winter, best in the afternoon and poorest in the morning.

(2) Over continental Europe at high elevations horizontal visibilties are best in the winter and best in the morning, poorest in summer and poorest in the afternoon.

(3) Over the sea at low levels the visibilities are best in winter and poorest in summer. Presumably the reverse holds at high levels, but observations are lacking as yet.

The fact that thermal stability favors good visibility in the upper air layers and poorer below, and thermal instability the reverse, is due not only to the characteristic difference in the level of active condensation in these two situations but also to the distribution of smoke and dust haze, the solid obscurative matter in the air. As has been pointed out, stability favors its collection in the lower levels, the formation of dense haze layers. Instability effects a rapid dispersion of this matter throughout all layers, by convection or by the greatly facilitated upward spread of advectively produced turbulence.

FRONTAL FOGS

There now follows a brief consideration of the less important because more transitory frontal fogs, or fogs closely associated with the fronts between air masses of different properties. From their nature it follows that their frequency is greatest where the passage of fronts is most frequent, or in the regions of greatest cyclonic activity. Because of their transitory and irregular nature, and because they occur in general in connection with such disturbed conditions and poor visibilities that they do not attract especial attention, fogs of this type have been very little studied. Since they usually occur in the course of the transition from one air mass to another of markedly different temperature, fogs of this type are usually attributed to mixing of nearly saturated

[43] See Köppen's figures, Landnebel and Seenebel, Ann. der Hydr. u. Mar. Met., 1916, p. 255.

[44] Ergebnisse von Sichtsmessungen in Karlsruhe mit vergleichenden Untersuchungen, Beiträge zur Physik der freien Atmosphäre, XIII Band, 1926.

air masses of different temperatures. Georgii's Mischungsnebel seems to include both frontal fogs and what I have called maritime fog. Yet Georgii himself remarks that Mischungsnebel can not be of long duration, for one can not have a mixing process in the course of the displacement of one air mass by another without the displacing mass rapidly becoming predominant.

A closer study of individual cases shows not only that the mixing process is not of long duration but that it is quite negligible for fogs on the ground. No doubt the higher fogs of the type considered under front passage fogs are due in part to the mixing process at the front some distance above the ground. But once the front becomes low enough to be close to the ground, the displacement of the existing by the following air mass takes place quite abruptly. A close analysis of ground fogs of the frontal type by the Bergen methods usually shows very clearly that the fog belongs definitely to one air mass or the other, definitely on one side or the other of a front which with a close network of stations is shown to be quite distinct and which remains distinct as long as the air masses keep their distinctive characteristics. The only person to have initiated a critical investigation of frontal fogs in the light of a careful air mass analysis is Calwagen, simply because he is the only investigator of fog who has had the necessary technique of analysis at hand. He had to a certain extent outlined frontal fogs and their causes before his work was so unfortunately cut short. Their classification must of necessity be relative to the type of front forming them. Hence they may be divided as follows:

I. Prefrontal fogs—occurring before a front, in the air mass being displaced.
- A. Before a warm front.
- B. Before an occluded front.
- C. Before a cold front.

II. Front passage fogs—frontal cloud systems which reach their lowest at the passage of the front, sometimes extending to the ground as genuine fog.
- A. With a warm front
- B. With an occluded front

$\left.\right\}$ Low migrating cloud systems—Calwagen's flyganda dimmor.

- C. With a cold front—line squall cloud.

III. Postfrontal fogs—occurring after a front, in the displacing air mass.
- A. After a warm front.

I. PREFRONTAL FOGS—OCCURRING BEFORE A FRONT PASSAGE IN THE AIR MASS BEING DISPLACED

A careful distinction must be made between real prefrontal fogs whose existence is due to the meteorological activity of the front and air mass fogs which have developed in the air mass in advance of the front quite independently of its action and simply remain lying in its path.

A. Prefrontal fog before a warm front. (*Calwagen's prefrontaldimma framför varm front.*)—This type of fog occurs in a zone immediately before an advancing warm front. If may be as much as 200 kilometers in breadth, but it usually lies completely within the area of precipitation or warm front rain area. It follows that the sky is always completely overcast. It occurs in its most marked form before a newly formed warm sector on a quasi-stationary front, hence with rapid cyclogenesis and with a very abrupt temperature and wind direction contrast at the front. Frequently at such a front there exist an abrupt wind shift of 90° (from SE. to SW., for example) and a temperature increase of 6° or 8° C. in a zone not wider than 50 kilometers. The fog lies entirely in the cold air and may be reported by every station in front of the active portion of the front to a distance of 150 kilometers. With the passage of the front it completely disappears. With an older less abrupt warm front this fog is usually less marked. Half of the stations in the prefrontal zone may report it and half not. But in every case it goes with the lowest temperatures, which excludes the possibility of its being the product of mixing of warmer and colder air masses. It is reported usually as dense fog, though presumably it does not reach the extreme density of a dense radiation fog. In the regions farther in advance of the front, where it first appears, it begins at the lowest elevations, as a low-lying wet-weather fog, with light winds. As the front approaches, it gradually grows in density and vertical extent, presumably extending upward to the low-lying clouds that mark the approach of the front.

There are probably two factors which are of prime importance in the formation of the typical prefrontal fog before a warm front:

1. Saturation of the cold prefrontal air mass by warm front rain. The colder air in advance of the front is frequently rather dry descending anticyclonic air. The first fine warm front rain from a. st. is usually completely evaporated before it reaches the ground. But with the increasing rainfall the cold air becomes rapidly humid, finally approaching saturation. The prefrontal rainfall is especially intense in the case of a newly formed warm sector with active cyclogenesis.

2. Adiabatic cooling by expansion. This expansional cooling takes place at any point in the prefrontal air mass in part as a result of the air drift, especially marked in the lowest layers, across isobars toward lower pressure; that is, simply the nongradient character of the lower winds. But even more important, in the case of active cyclogenesis, is the general fall of pressure which takes place in the whole region of development. In such cases the local pressure change in any element of the air mass is due much more to the deepening over the whole field of pressure than to the element's change of position in the field of pressure. This pressure deepening is most rapid directly in advance of the warm front, hence is most effective in producing fog here.

The markedly greater fog-producing effect of these two factors before a newly formed rapidly developing warm sector with its sharply marked warm front explains why prefrontal fog before a warm front is characteristically more distinct when the warm front is abrupt than when it is diffuse. The case of fog with a very diffuse warm front that marks the first inflow of T. A. after a long prevailing stagnant anticyclone is entirely different. In that case there is usually very little prefrontal rain and no pressure deepening due to cyclogenesis. If there is fog in the cold air mass, it is the remainder of inversion fog, which, it was remarked, is most frequent often in the western portion of the anticyclone, where the inversion becomes low. Such fog is always under the inversion, which, according to Georgii's aerological data, remains intact almost to the ground. If there is fog after the retreat of the inversion, it is the fog characteristic of the foremost transition portion of a general T. A. invasion, as was pointed out in the discussion of T. A. fog. Genuine prefrontal fog before an active front does not often merge into an inversion fog further in advance of the front, because it occurs in unstable rapidly changing conditions, which does not permit of the formation of true inversion fog. It may, however, merge into a previous maritime fog

over land in such a manner that it is difficult to say which type is prevailing.

One other characteristic condensation form before a warm front requires special mention. When such a front advances against a high coast line or a range of hills or mountains there is a certain amount of forced ascent of the cold air between the front and the obstacle. If the air is nearly saturated this results in the formation of dense low stratus, which is thickest against the obstructing barrier and appreciably lowers the effective level of the warm front cloud deck. It may appear at only a hundred meters and be reported as high fog. In such a case it may form an unbroken cover and extend solidly upward to the original frontal cloud system. Similar semidetached low-lying cloud frequently appears over high woodland, sometimes resting almost on the tree tops. The fact that poorer visibility usually prevails over high woodland in rainy weather is generally recognized by the German air pilots. Such prefrontal low cloud formations are extremely unfavorable for air traffic, for as soon as the pilot can not count on sufficient ceiling to clear all ground obstacles they are quite as obstructive as the worst high fogs. It is quite probable that as the front becomes low the mixing at the front resulting from the turbulence caused by ground obstacles to the air flow is as important as cooling by forced ascent in effecting low stratus formation.

B. Prefrontal fog before an occluded front.—The prefrontal phenomena before a newly occluded front are very little different from those before a warm front. But with the occlusion, all characteristic warm front phenomena reach their maximum, from then there begins a gradual deterioration. The general rapid cyclogenesis ceases, the cyclone begins to fill, pressure fall tendencies before the front become much smaller or disappear, the precipitation decreases in extent and intensity, and the rate of advance of the front becomes less. Exactly the same prefrontal fog, or under favorable conditions, low cloud formation may occur before an occluded front as before a warm front. But, as has been pointed out, all the factors upon which these formations depend are weaker after occlusion. Hence the formations themselves have usually reached their most marked development and are already in part weakened or dissolved. A regeneration of the front can also lead to a regeneration of all the condensation phenomena.

C. Prefrontal fog before a cold front (barometric fog) (Calwagen's prefrontal dimma framför kalt front).—The prefrontal fog before a cold front differs from that before a warm front or occluded front in that it is formed in the T. A. sector. In this case there is not the front rain to effect the saturation of the fog-forming air mass. But, as was pointed out in the discussion of T. A. fog, the lower layers of such an air mass acquire a continuously increasing relative humidity due to gradual surface cooling, even to the extent of weak fog or stratus and drizzle formation. In the warm sector of a rapidly developing disturbance the cooling effect of adiabatic expansion [45] by the two processes of the air flow across isobars toward lower pressure and general deepening of the depression, superposed on the general surface cooling, may form fog throughout the warm sector. This formation is most marked directly in advance of the cold front, for in this zone the most rapid fall of pressure within the warm sector is occurring. The cooling of a warm sector by adiabatic expansion in a case of intense cyclogenesis may be so great that temporarily the T. A. can be cooled in its lower layers to a slightly lower temperature than that of the sea surface over which it was previously cooled if the poleward temperature gradient of the ocean surface is very slight. In this case one of the principal distinguishing characteristics of a T. A. mass is destroyed. But in the ordinary T. A. current, and with the ordinary T. A. fog and drizzle, such cooling by expansion plays a comparatively slight rôle.

[45] An extreme instance of this phenomenon, where the formation of a. st. and typical warm front rain within the warm sector was attributed by Bergeron and Swoboda to adiabatic cooling by expansion, is treated in detail by these authors in their paper, Wellen und Wirbel auf einer Quasistationäre Grenzfläche über Europa, 1924, pp. 103–104.

II. FRONT PASSAGE FOGS OR MIGRATING LOW-CLOUD SYSTEMS

The low-cloud systems that belong to the passage of a front are not usually fog in the proper sense of the word. With the possible exception of an occasional warm front passage, it is only high and exposed situations that are enveloped in such low-cloud strata. But they require special mention in any consideration of fog for aviation forecasting, where the elevation of the base of low clouds is of extreme significance. The movement of a frontal low-cloud system is the same as that of the front to which it belongs. Therefore they have been called migratory low-cloud systems in contrast to the stationary low stratus cloud of the anticyclonic high inversion fog. Since the strongest winds in a disturbance occur with the passage of the front, the frontal low cloud strata frequently appear with strong winds, while the anticyclonic stratus occurs with very light winds.

A. Fog with a warm front (Calwagen's frontal dimma).—The progression from ci. through ci., st., and a., st., to low ni., which characterizes the approach of a warm front is quite generally recognized as the cloud system resulting from the upward flow of warm air over the gradually subsiding and retreating cold air mass in advance. Upon the close approach of the front the lowering cloud deck reaches a certain minimum elevation, which, theoretically at least, represents the height to which surface air in the T. A. current must be raised in order that condensation may occur. This height may be readily computed from a knowledge of the temperature and humidity in the lowest layers of the T. A. mass. In the limiting case, when the T. A. mass is quite saturated in the lowest levels, this elevation becomes zero, which gives the comparatively infrequent case of a dense surface fog formation at the passage of the front. Such fog will then persist as dense T. A. fog in the foremost portion of the T. A. current. But as was pointed out under T. A. fog, the typical T. A. obscurity is not a dense fog, but rather drizzle and low stratus. Dense surface fog is a rather rare and extreme case, occurring principally over very northerly seas, or over a snow-covered continent. Therefore, ordinarily the warm front passage is marked by low stratus, but not real surface fog. After the passage of the front, visibilities gradually improve slightly as the T. A. current becomes fully established, but no marked improvement can occur until the passage of the cold front brings the P. A. invasion.

The orographical influence of high coast lines or ranges of hills or mountains, as was pointed out under the discussion of prefrontal fogs, has the net effect of lowering the cloud base before and during the front passage. The cause of this orographical lowering of the base of the cloud deck is doubtless in part cooling of the subfrontal air mass by forced ascent, and in part the mixing of the two air masses caused by the resulting turbulence. With the approach of the front these lower cloud formations become solidly united with the low cloud system of the front in one thick cloud deck. Thus, on the

west coasts of Norway or Scotland it is quite common to find the cloud base of the approaching warm front at only 100 to 200 meters' elevation above the sea. The high winds that almost invariably accompany the passage of such a front result in a characteristic high velocity of the low clouds. The frequent high "Flying Fogs" (Flygand Dimmorna), which have been so much remarked on Scotland's west coast, are attributed by Calwagen to frontal low cloud systems.

The direction of movement of the warm front cloud system is the same as that of the front, which is usually considerably to the right of the apparent movement of the lower clouds themselves. The frequency of such cloud systems varies with the number of front passages, or with cyclonic activity. They are usually lower and denser in winter. In summer they occur only over the the sea or along the coasts. The summer insolational modification of T. A. characteristics over the continents is such as to render the formation of a very low warm front cloud system almost impossible.

B. Fog with an occluded front.—The conditions with the passage of an occluded front are approximately the same as with a warm front. Certain characteristic differences should be mentioned, however. (1) The occluded front cloud system has passed its greatest development and is beginning to deteriorate. (2) Since with the occlusion of the warm sector of a disturbance the warm air is completely displaced at the ground, it is no longer possible in any case for the cloud system to extend to the ground as a real surface fog, for the front cloud system and fog belong to the T. A. mass. (3) The passage of an occluded front, instead of being followed by the characteristically poor visibility of the T. A. mass, is followed by the characteristically clear P. A. Instead of the low st. cloud of the warm sector, there is the somewhat broken cloud deck of cu ni, blue sky being visible between showers. The only case where real fog and very poor visibility is possible after an occluded front passage is after the front has passed some distance inland, in winter, and is followed by an invasion of M. P. A. In this case maritime fog may follow almost immediately on the passage of the front, but the same process which leads to the rapid modification of the temperature gradient in the M. P. A. mass results in the rapid dissolution of the front itself, by the destruction of temperature contrasts aloft.

C. Fog with a cold front.—The typical cold front passage is usually marked by a heavy shower or squall line with a marked wind shift. It may be preceded by prefrontal fog in the T. A. mass with very poor visibility, but its passage, as in the case of the occluded front, brings a marked change for the better, with P. A. showers and broken cloud deck. Also as in the case of the occluded front, the shower or squall cloud itself can not rest upon the ground as low fog, except on very elevated locations, for the cause of cloud formation is the underrunning and forcing up of the warmer air mass by the following cold air. But the heavy rain, low cloud, and strong shifting wind which often accompany the cold front, although of short duration, may be very dangerous for the aviator. The direction of movement of the cloud system is that of the front, and not of the winds or clouds in advance of the front. A cold front sufficiently advanced inland, may, like an occluded front, be followed by maritime fog, but never when it still persists as a vigorous front or squall.

III. POSTFRONTAL FOGS

There is only one type of fog which can properly be classed as a postfrontal fog. It has already been considered under T. A. fog, but it is to a certain extent dependent upon the immediate preceding passage of a warm front. It is the zone of fog which often appears in the foremost transition porton of a T. A. current which is invading a region previously occupied by a stagnant cold air mass. Its formation is the result of cooling by contact with the previously thoroughly cooled ground, and also by mixing with remnants of the cold air mass left behind natural barriers. It so far as this mixing process is responsible for the formation, it is properly a postfrontal fog. Probably this is the most extensive rôle played by the mixing process in a ground fog formation.

After cold fronts or occluded fronts postfrontal fog is quite impossible, due to the properties of the following cold air masses. Only martime fog can follow close after such fronts, far inland, but it is in no sense dependent on the passage of the front for its formation. It can form quite as well hundreds of miles behind the front as it can immediately behind. Therefore it is purely an air mass fog, and in no sense a postfrontal fog.

Frontal fogs as a class are comparatively unimportant. Their frequency and duration are such that they have no detectable influence on climatic statistics. On the other hand, due to their rapid movement and often unexpected appearance they constitute a real menace to aviation. An understanding of their causes and a method of for casting them is quite essential.

PART III

FOG FORECASTING FOR AVIATION INTERESTS

Any general discussion of fog forecasting must be based on theoretical considerations rather than on principles applied in practice, for the simple reason that there is no developed system of practical fog forecasting. Most weather services concerned especially with maritime interests make fog forecasts for coastal and open-sea stretches. This is done especially by the Deutsche Seewarte and to a certain extent by the Norwegian and British meteorological offices. But the fogs with which they are concerned are especially sea fog and monsoon fog, which are two of the most regular and readily forecast of fogs. Such fogs when once formed are rather persistent, and the conditions favoring their movement or dissipation are such as to render them fit subjects for forecasting. They are not, however, usually forecast previous to their first formation and appearance.

In the case of the more variable land fogs the problem is much more difficult. Here the weather services most interested in a correct fog prognostication are, of course, the services established for air line protection. On the Continent of Europe, especially in Germany, the meteorological service for aviation purposes is much further developed than the ordinary service. But the whole attention of these aviation services is directed not toward making better forecasts for some time in the future but rather to getting a complete picture of prevailing conditions in the region desired. On the basis of very numerous observations, detailed forecasts are prepared for the pilots covering their respective routes for the next three or four hours. Special warnings are received from all stations and sent out to the pilots in the air of the appearance of fog, squalls, low cloud, etc. The movement of fog zones already formed is very carefully noted and forecast for the following few hours, but usually the forecasting of fog is not attempted previous to its first appearance. Occasionally the formation of local ground fog is forecast. The dissipation of ground fog can usu-

ally be forecast with some certainty, but the forecasting of the dissipation of the more stable types is attempted only as successive reports show a progressive change to be taking place.

The lack of any completely developed system of practical fog forecasting necessitates a theoretical rather than a practical consideration of the subject, but at the same time the factors which may decisively influence the formation or nonformation of fog in any typical instance are so numerous, that no discussion can be made general. There are no general principles that may be applied in all cases of fog formation. Each group of fogs must be considered separately. The factors which may be of importance in the formation of fogs of that group will be discussed, and then will follow a special consideration of each type of fog in the group with its significant characteristics.

A. AIR MASS FOGS

The problem of forecasting an air mass fog resolves itself into two parts, namely, (1) to determine what air mass will prevail at the time and place for which the forecast is to be valid, and (2) to determine what characteristics that air mass will then possess. The first part of the problem is quite the same for fog forecasting as for the forecasting of any other meteorological element. It depends simply upon the correct prognostication of air mass movements, and presupposes a method of air mass analysis which correctly bounds the distinctly homogeneous air masses in accordance with their characteristic properties. This part of the problem will receive no further consideration here.

The determination of the properties which an air mass will possess at a certain time in the future, with sufficient precision to forecast fog, is a very complicated problem. This follows from the extreme sensitiveness of fog to a very slight change in the properties of the air mass, and the great number of factors capable of producing such slight changes. For the consideration of fine distinctions in all the properties of an air mass, together with the factors which are at work to change these properties, the Bergen methods of analysis are best suited. They are the only methods sufficiently comprehensive in their treatment of all air mass properties, and precise enough in their estimate of the significance and causes of the minor variations in these properties.

The determination of the future properties of an air mass must be made from a consideration of its present properties and the modifying influences to which they will be subject in the meantime. The present properties of any air mass are fixed to a rough approximation as soon as the mass is classified as polar, tropical, or transitional. The properties of the mass of most significance for fog formation are:

(1) Absolute humidity, especially in the lower layers. Both the cooling of the mass by direct radiation to space and the temperature at which saturation will be reached are dependent upon this property. In both of these respects a concentration of moisture in the lowest levels is favorable to fog formation.

(2) The vertical temperature distribution. Both the relative humidity distribution, assuming a constant absolute humidity, and the effectiveness of convective or mechanical turbulence in carrying moisture aloft are dependent on this property. In both of these respects a steep temperature gradient is unfavorable to fog formation.

(3) The horizontal pressure distribution. The air mass flow, hence wind velocity and production of mechanical turbulence are dependent on this property. A steep horizontal gradient is unfavorable to fog formation.

The modifying influences to which the air mass properties will be subject in the near future are in part dependent upon whether the mass will be in motion (characteristic of advection fogs), or whether it will remain stagnant (characteristic of radiation fogs).

1. ADVECTION FOGS

In the case of marked advection the significant air mass properties may be subject to the modifying influences considered below:

(1) *Absolute humidity.*—(*a*) *May be increased* by evaporation from a water or damp ground surface, or from falling rain or snow. For air mass fogs the evaporation from a water surface is the most important. But this process alone can never produce saturation except as $T_s-T_a>0$, which as has been pointed out is an exceptional condition to result in fog formation.

(*b*) *May be decreased* by the deposit of dew, or by the condensation and falling out of rain or snow. The drying effect of a mountain range on an air current forced to blow over it is the most marked instance of decrease of absolute humidity by precipitation.

(2) *Vertical temperature gradient.*—(*a*) *May be increased* by relative heating of the lower levels or by relative cooling of the upper levels. The first process may occur by contact with a warmer surface ($T_s-T_a>0$), by direct absorption of solar radiation, or by the condensation of water vapor. Generally $T_s-T_a>0$ holds over land in the warm season and by day, over water in the cold season and by night. The direct absorption of solar radiation takes place by day, and to the greatest extent in the air layers where the absolute humidity is greatest, hence normally the ground layers. The condensation of water vapor takes place in the lowest layers only in the course of fog formation. It is most rapid with the excessive steaming over a markedly warm water surface. The second process, the relative cooling of the upper air layers, may take place by a net direct radiation of heat to space, or by the evaporation of condensation products. These are of minor importance, the cooling by direct radiation perhaps playing an appreciable rôle at an upper inversion surface at which there occurs a marked decrease in absolute humidity or dust content of the air. Such a surface is an active radiating surface.

(*b*) *May be decreased* by relative cooling of the lower air levels or by relative heating of the upper levels. The first process may occur by direct contact with a colder surface ($T_s-T_a<0$), by a net direct radiation to space, or by evaporation of condensation products. Generally $T_s-T_a<0$ holds over land in the cold season and by night, over water in the warm season and by day. The net direct radiation of heat to space takes place at night from the air layers where the absolute humidity is highest, or normally the ground layers. Cooling by evaporation is relatively unimportant. The second process, the relative heating of the upper air layers, may take place by direct absorption of solar radiation, by condensation, and by adiabatic compression. A good radiating surface, at a humidity and dust discontinuity, is also a good absorbing surface. Heating of upper air levels by condensation is quite important in the cu. ni. convection of unstable M. P. A. Heating by adiabatic compression of the upper air layers is marked in the upper

portion of a developing anticyclone, where it usually results in the formation of a large inversion.

(c) *A constant vertical temperature gradient*, by a corresponding change of temperature at all elevations, occasionally may be of significance for fog formation. Such is the case of cooling or heating by adiabatic expansion or compression which accompanies the deepening or filling of a cyclone, and the case of cooling by the forced ascent of the fog-forming air mass caused by orographical obstacles.

(3) *Horizontal pressure gradient*.—(a) *May be increased* by a convergent air flow and resultant crowding of isobars. This is characteristic of cyclonic development, especially of the northward flow of T. A. masses.

(b) *May be decreased* by a divergent air flow and resultant spreading of isobars. This is characteristic of anticyclonic development and the southward flow of P. A. masses.

The detailed consideration of each kind of advection fog follows, first those characterized by $T_s - T_a < 0$, then those for which $T_s - T_a > 0$.

MONSOON FOG

In the forecasting of monsoon fog it is necessary to distinguish between the narrowly coastal phenomenon due to the daily exchange of air between land and sea, and the much more extensive irregular formation due to a steady drift of air during a number of days from land to sea. The *daily* monsoon fog is extremely regular where the temperature contrast between land surface and sea surface is great, and disturbing influences slight. In such a region, as on the California coast, once the normal condition is established, fog may be predicted to appear regularly as long as no cyclonic activity is foreseen of sufficient intensity to interfere with the regularity of the daily sea breeze. In regions where the *daily* monsoon circulation is weaker, as on the western coast of Norway, where the ocean temperatures are characteristically warm (for the latitude) instead of characteristically cold, the forecasting of fog becomes a very delicate problem. It is absolutely essential for the forecaster to be thoroughly acquainted with the characteristic peculiarities of the coast region, and to take into account the insolational heating of the land during the preceding days, the prevailing relative humidity of the warm air mass, and the surface sea temperature. Once the fog has made its appearance, it can be forecast for the following days as long as there is no marked change in conditions.

The distance inland to which the daily monsoon fog will penetrate depends upon its vertical extent and density, the strength of the sea breeze, and the value of $T_s - T_a$ when the foggy air mass comes over land. This difference, always negative over the sea where the fog formation occurs, is always positive when the fog comes on shore, hence, warming of the air mass from below and dissipation of the fog begin at once. On the Norwegian coast the fog is not exceptionally dense, and usually about 1,000 to 1,400 feet in depth as it comes in from the sea. In the *early* afternoon it never penetrates more than 20 miles inland from the outlying points of the coast. Frequently it does not advance inland at all. But with the setting of the sun and beginning of radiation cooling over the mountains along the coast the moisture which has been coming in with the sea breeze appears as a low stratus, often growing down to the ground before morning, as surface fog. Such formations may extend 30 miles inland from the outermost coast. No doubt the more potent daily monsoon fog formations such as those on the California coast may be both denser and deeper, and penetrate further inland than the distance mentioned above.

For inland aviation this type of fog has no significance. For coastal flying it can be a great nuisance in certain sections. However, its regularity of occurrence and its limited horizontal extent are mitigating factors. Presumably as long as only the daily land and sea breeze is concerned, the fog does not extend out over the sea to a much greater distance than it is brought inland in the late afternoon, though observational material is rather lacking on this point. But as soon as the more persistent air currents enter into the situation the conditions are very different.

In the case of the more persistent and widespread monsoon fog, of which an excellent illustration has been discussed, there is found the best opportunity of forecasting fog from a consideration of simple air mass properties. In the first place, there must exist a pressure distribution that will bring a steady flow of warm air from the land to the sea. As this air mass cools over the water, the essential condition for the formation of an extensive monsoon fog is the absolute humidity which characterized the lower levels of the mass when it left land.

Unless this moisture content is such that saturation will be reached at a temperature appreciably above the sea surface temperature, fog formation is unlikely. Evaporation from the cold sea surface can not raise the moisture content of the air mass sufficiently to render saturation possible at a temperature higher than that of the water surface except for the slight amount which can take place at the expense of the heat content of the air. If the outflow of warm air is so marked that air temperatures over the sea show a considerable increase, and if humidities are not excessively low, a general fog formation can be predicted with certainty as the temperatures begin to fall in the same air mass. In the case considered previously the air temperature at Jan Mayen one day before the first fog appearance was 10° C. above the sea temperature, which is very unusual for that station. Fog first appeared 24 hours later with an air temperature still 6° C. above the sea surface temperature. Complete stagnation of the foggy air mass with gradual weak anticyclonic development as the air cools is the condition favorable to the extreme development of the fog. Presumably under such conditions it reaches a thickness equal to that of a high sea fog, some 2,500 or 3,000 feet according to Taylor.

The persistence of such a fog when once formed makes this extensive monsoon fog the type of ready formed fog which can most reliably be forecast long in advance, simply on a basis of the movements of the air mass. This is recognized in England, where in summer a wind off the North Sea, if fog has already formed there, is certain to bring the fog inland. Summer fog over the North Sea is nearly always of the monsoon type. It may move many hundreds of miles over the sea, and from 100 to 200 miles or even more inland without dissipation. The rapidity of the dissipation depends on its thickness, density, and the difference $T_s - T_a$. No doubt quantitative rules for this dissipation can be derived empirically from sufficient observations, or from theoretical considerations. Usually, however, the sensitiveness of fog to changing conditions and the multiplicity of modifying influences is such that quantitative mathematical treatments are useless.

For ordinary shipping this extensive monsoon fog is of much importance, but for inland aviation it figures only in the comparatively rare event that it is brought far inland. These cases can always be forecast with the same accuracy as air mass movements. For transoceanic flying fog is less of a hindrance than for inland flying, for the aviator can fly above it as long as it is not necessary to come down. Present methods of orientation by radio make this more practicable than formerly. Furthermore, a forced descent through fog over the water does not involve the same danger of collision with obstacles or difficulty in finding a landing place that it does over land.

SEA FOG

In general the same considerations hold for the forecasting of sea fog as for the extensive monsoon fog. The only difference is that the warm air mass comes from a relatively warm water surface instead of a warm land surface. This means that the absolute humidity is always great. The temperature contrast and therefore the cooling of the warm air mass is usually less than is the case of monsoon fog, but the originally high absolute and relative humidity necessitates a comparatively small degree of cooling. Almost invariably a moderate flow of air from warmer to colder water surface will result in fog formation over the colder water. How quickly this formation will occur depends upon the horizontal temperature gradient in the water surface, the rate of flow of the air mass, and its temperature and absolute humidity. If the air mass has previously been long at rest or in slow movement over the warmer water, it can be counted on in its lower layers to be nearly saturated at about the temperature of the water surface it occurs over. Strong wind velocities effect a too rapid dissipation upward of moisture and cooling to permit of dense fog.

The vertical extent of sea fog has been studied by G. I. Taylor off the Newfoundland Banks on board the *Scotia*, in a series of kite ascents. As he remarks, it may occur so low over the sea that on the deck of a large ship the visibility is only a 100 feet, while the masts extend completely above the fog. This probably represents an early stage in the development, with very slight winds. A normal depth of sea fog seems to be from 300 to 1,000 feet, and the extreme depth observed by Taylor to be 2,500 feet. The fog when once formed is persistent. When carried over warmer water it dissipates but slowly. For both monsoon fog over the sea and sea fog the dissipating effect of heating by the direct absorption of solar radiation seems to be comparatively slight. They develop and persist equally well, as far as can be judged by general observation, under clear or overcast sky. In general, however, monsoon fogs are characterized by clear skies, sea fogs by overcast skies, simply because insolational heating over land and absence of cyclonic activity are favorable to monsoon fog formation, while the general transport of air northward under weak cyclonic activity is favorable to sea fog formation in those localities where there are rapid changes in sea surface temperature. Its dissipation is usually dependent upon the blowing up of a fresh to strong wind or the displacement of the foggy air mass by one of different properties. For aviation it has no significance except in transoceanic flying, where the only distinction to be made between it and extensive monsoon fog is that it is less likely to affect coastal districts.

TROPICAL AIR FOG AND HAZE

As with monsoon fog, the result of land and sea temperature contrast, and with sea fog, the result of local sea surface temperature contrasts, so with tropical air fog, the result of the general poleward gradient of all surface temperatures, the essential factor to be considered in the forecasting of the fog is T_s–T_a. But with tropical air fog, when the air mass concerned is really of subtropical origin, the modifying influences affecting the mass in its long journey northward are more important than its original properties. Such an air mass, at least over western Europe, always leaves its source rather warm and dry. No fog will appear in it before it has been very considerably cooled in its lowest layers, or else has suffered a very considerable increase of its absolute humidity. Therefore tropical air fog is characteristic only of northerly regions, after the air mass has moved a long distance over cooler surface. Due to the thermal stratification caused by the long cooling from below, and the fact that only the strongest T. A. currents can move so far northward, this fog usually occurs with fresh to strong winds. Over the sea drizzle and a moderate degree of fog may always be forecast with fresh to strong winds between south and west southwest when the air mass is of southerly origin. The further north the latitude and the more abnormally cold the sea surface the greater will be the fog density. This type of fog is always so marked on the west coast of the British Isles that it is recognized and forecast by the English forecasters. It also usually forms in the passage of the T. A. current over a continent in winter, especially over a snow surface, but never in summer. In summer the T. A. current gives rather a dry heat haze and opalescence which is always characteristic of T. A. masses in the absence of sufficient cooling to give fog or drizzle. In no case whatsoever is T. A. accompanied by really good visibility. The appearance of fog comes gradually with the northward progress of the air current, so that it never appears unexpectedly as a dense formation without previous warning. Therefore fog need not be forecast upon the approach of a T. A. current unless it has already appeared to some degree in the current. Furthermore, it is always most marked in the forward portion of the current where the cooling of the air mass is most pronounced. This gives frequently a distinct moving fog zone whose position may be forecast with precision once it has formed. In the warm sector of a rapidly developing cyclone the fog formation is greatly favored by the marked adiabatic cooling by expansion.

In the case of a warm air current moving northward where the air mass is not really of subtropical origin but rather M. Trans. A., fog is formed in exactly the same manner, but certain distinctions must be made. In the first place, such an air mass is usually more nearly saturated initially, hence requires less modifications, and usually gives fog more quickly. In the second place, due to the smaller amount of cooling it has undergone, and the frequent persistence in the upper levels of the original P. A. instability, its stratification is less stable than that of real T. A., hence fog can not form or persist with strong winds. Finally, such an air mass in the absence of fog or drizzle is never characterized by the dry T. A. haze or opalescence, but by rather good visibility. Only real T. A. can show opalescence.

Tropical air fog becomes as a rule less dense at a given point after the current has been maintained for some

time. But the complete dissipation of T. A. obscurities may be forecast only for the complete displacement of the T. A. mass by air masses of northerly origin.

For inland aviation tropical air fog is of significance only in winter, and only in rather northerly latitudes. The haze or opalescence may always be counted on with T. A. invasions, but it is not usually of a density sufficient to embarrass an experienced aviator. Over the sea the fog occurs both summer and winter, but is always more pronounced in winter, apart from the special monsoon form, which occurs only in summer. The typical tropical air fog is not exceedingly dense, but is accompanied also by a low stratus deck and drizzle, a combination which makes flying practically impossible. It is not possible to fly above the surface T. A. fog without flying above the stratus formations also. It will rarely be a hindrance for more than 24 hours, because in regions northerly enough to have the real fog formation it is seldom that the T. A. invasion lasts more than that. The fog is always most marked in the northerly portion of the T. A. invasion and with marked cyclonic activity, hence the displacement by P. A. masses is certain to occur before long.

ARCTIC SEA SMOKE

The steam fogs due to the advection of cold air over warmer water are of little practical significance, but will be considered briefly. Whenever an air temperature prevails over a water surface which is less than that of the water surface ($T_s - T_a > 0$) there is present the possibility of saturation of the air by direct evaporation from the water surface. When this saturation takes place sufficiently rapidly there occurs the visible steaming which in the arctic regions is called Arctic Sea smoke. The density of such visible steaming is dependent entirely upon the rapidity with which saturation can take place; therefore, upon the size of the difference $T_s - T_a$, the air temperature, and the absolute humidity of the air.

Whether this steaming will produce real fog or not depends entirely upon the vertical temperature gradient. In order to have fog produced, the gradient must be only very slight at least, probably a marked inversion is necessary. Such a condition can occur over warm water only very locally in regions where there is a copious supply of cold air. Therefore this type of fog need never be forecast over the open sea, except at the edge of the Arctic ice. It may occur over an arm of the sea which is nearly surrounded by very cold land surface if winds are light. There it may be forecast under a condition of extreme cold (anticyclonic radiation type) and light winds. Under such conditions it may become a very dense fog. The Bay of Fundy, the Baltic Sea, and the northern Norwegian Fjords are subject to it in winter. It will not appear at an air temperature warmer than $-6°$ or $-8°$ C. in these regions. For aviation it is of negligible importance.

EARLY MORNING AUTUMN STEAM MISTS

The forecasting of these mists is exactly the same in principle as that of the Arctic Sea smoke. As in the case of the Arctic phenomenon, there is no fog formation unless there is a marked low inversion to prevent the convective dissipation of the steam warmed air. This condition is furnished over inland lakes, rivers, etc., whenever there is a marked depression of the land surface, by the gravitational flow of radiation cooled air from the surrounding ground surface. Furthermore, the fact that such radiation cooled air is nearly saturated or even quite saturated (radiation ground fog) renders the steaming visible (because supersaturation is so quickly reached) at higher temperatures than Arctic Sea smoke is usually visible. The effect of almost complete initial saturation of the air is shown in the rising of steam mists over woods and valleys after a heavy warm rain. Probably the fact that slightly cooler air often follows such a rain favors the steaming. But such steaming never forms real fog; it rises too quickly, due to the absence of inversion. An extensive fog is never formed over a warm moist land surface, as is frequently assumed in the explanation of general fogs.

In general, whenever ground fog of the radiation type may be forecast (discussed below), then steaming over water bodies may be forecast for the same region. Whether this steaming will intensify the ground fog or dissipate it locally depends upon the local topography, the temperature difference $T_s - T_a$ over the water and the amount of evaporation necessary to produce saturat on in the air. The depth of the cold air layer depends on the topography. The greater the value of $T_s - T_a$ the greater the steaming, but also the more rapid the formation of convective instability. High relative humidity and low temperature in the air mass mean rapid saturation. Hence, in north temperate regions this steaming is more likely to cause dense fog in the winter than in the autumn, for snow cover on the ground favors great radiation cooling, while at the same time the water surface has become sufficiently cooled so that $T_s - T_a$ is not excessive, and the general low temperatures mean that only a small amount of evaporation is necessary to produce saturation. This accounts for the observation of Kleinschmidt in the region of the Bodensee in Germany, that in the autumn the frequency of fogs over the Bodensee was much less than over the surrounding country, but later in the winter became slightly greater. At the same time, cumulus convection was much greater over the lake both autumn and winter than over the surrounding country. For any particular locality the question of whether the steaming will cause formation or dissipation of fog is best determined from a study of accurate records in the region concerned. In early autumn in flat country even a very small water surface has always a marked preventive influence on the formation of radiation ground fogs, locally, as is so well recognized by the German aviation pilots.

The significance for aviation of autumn steam mists as fog producers is very slight, for they are extremely local, and when productive of fog the fog is local. Such local formations can be avoided by a pilot that knows the region.

Furthermore, the fogs formed by this process are quite shallow, probably seldom exceeding 200 meters. The real significance for aviation of the warm water steaming lies in its fog dissipating effect. A river course may be the only route which can be flown through an early morning ground fog of the radiation type.

2. RADIATION FOGS

In general radiation fogs, in contrast to advection fogs, are favored by almost complete stagnation of air mass movement. Therefore, the forecasting of fogs of this type is dependent upon a consideration of the modifying influences of *local* conditions upon the air mass already present and at rest rather than on a consideration of the modifying influences upon a distant air mass of the route traveled by that mass. In this case of the stagnating air mass the same properties of the mass are significant

for the formation of fog, absolute humidity, vertical temperature distribution, and horizontal pressure distribution, as in the case of the advection fogs. But in this type of situation the lightness of the wind velocities is such as to permit of a sufficient local concentration of active nuclei of condensation so that this becomes a fourth property of the air mass significant for fog formation. The respective modifying influences which affect the air mass properties are of rather different relative importance in the radiation fogs, and therefore require brief consideration, as follows:

(1) *Absolute humidity.*—This property is comparatively stable in a stagnating air mass, for evaporation from a water surface is greatly diminished in the absence of wind, and in the low temperatures characteristic of the lower levels of such a mass, precipitation is usually lacking, and the drying process effected by mountain ranges on advective air currents forced to pass over them becomes impossible in a stagnating mass. The decrease of absolute humidity by the deposit of dew is favored, but this process is always insignificant quantitatively at more than 1 meter above ground.

(2) *Vertical temperature gradient.*—This property is comparatively variable in a stagnating air mass, because the lightness of the prevailing wind permits of a cumulative effect of the modifying influences in producing thermal stratification. These modifying influences are the same as with the advection fogs, except that the radiational cooling and insolational heating of the ground surface which is especially favored by this type of situation is so pronounced that direct conduction of heat to or from the underlying surface assumes the most important place among these influences. The heating of the upper layers by adiabatic compression in the course of an extensive anticyclonic development becomes much more important than in the case of advection fogs.

(3) *Horizontal pressure distribution.*—Since radiation fogs are always characterized by light winds, the horizontal pressure gradient is never steep. Due to the sensitiveness of these fogs to comparatively light winds, this is an essential conditions, so that the weakening of the pressure gradient by the divergent air flow which accompanies gradual anticyclonic development is often an important modifying factor.

(4) *Density of hygroscopic nuclei of condensation.*—This is a property which is subject primarily to local variations, though when conditions are favorable it may vary singificantly throughout the air mass. The modifying factors to be considered are (1) the location of sources of pollution (industrial regions) which supply the active nuclei, (2) the prevailing winds (both direction and velocity) which determine the local distribution of these nuclei within the air mass, and (3) the action of the sun's rays in increasing the hygroscopic properties of the nuclei.

The detailed consideration of each type of radiation fog follows.

GROUND FOG

Ground fog, or radiation fog accompanying a ground inversion, probably is a greater nuisance to inland aviation than any other type of fog. In the eastern United States, where certain other types of fog which are very frequent in Europe are comparatively rare, it is quite possible that this ground fog causes more trouble than all other types combined. This is not due to its greater density, extent, or persistence. It is usually only a morning fog, occurring more or less locally and probably seldom reaching a depth of 200 meters. But its significance lies in its frequency, irregularity, and the great geographical range where its occurrence is possible. It may develop over almost any inland surface during clear calm nights, and the great irregularity of this occurrence depends upon a multitude of local modifying conditions which render its forecasting very difficult. There must be taken into account both the general air mass properties and the local conditions. It is impossible to forecast this fog for a definite locality without a very particular knowledge of these local conditions.

Considering first the general air mass properties which are significant for the development of ground fog, the fact that it is characteristic of aging anticyclonic conditions shows that its formation occurs in C. Trans. A. masses. As has been pointed out, the principal cooling processes are by direct radiation of the lower air layers to space, and especially by direct contact of the lowest air layers with a radiation cooled ground surface. At any rate, radiation to space is necessary, hence the first requisite for radiation fog is a clear or at least partly clear sky. In the second place, since this cooling must not be too rapidly dispersed by turbulence, the wind velocities must be light. On the other hand, some slight turbulence is necessary if the cooling is to extend more than 3 or 4 feet above the ground (limit of effect of cooling by conduction in a single night), therefore a very light wind is favorable. According to Taylor, in only 2 out of 70 instances of radiation-fog formation at Kew was the wind velocity at 8 p. m. of the evening before greater than 5½ miles per hour. Hence usually a wind at 8 o'clock of more than 6 miles per hour seems to be enough to make a no-fog forecast. In the third place, the temperature inversion that always comes with the ground cooling which effects ground-fog formation appears early in the evening. Probably the complete absence of a ground inversion at 8 p. m. is another condition sufficient to warrant a no-fog forecast, but this rule requires observational confirmation.

Finally, the absolute humidity must not be excessively low, or the cooling necessary to effect saturation will not be attained. As has been pointed out, although radiational cooling of the ground is favored by low absolute humidity of the air above, this effect is more than outweighed by the increased direct radiational cooling of the air and the decrease in the amount of cooling necessary to produce saturation which goes with high absolute humidity. Usually, except in arid regions, it will not be low, because the great insolational heating by day in clear, calm anticyclonic situations results in considerable evaporation from ground and water surfaces. The cooling near the ground already early in the evening is usually such as to cause a high relative humidity and deposit of dew. Probably the absence of any deposit of dew on the grass at 9 p. m., or by the time of complete darkness, is another condition warranting a no-fog forecast, but this rule also requires observational verification. Then the general conditions necessary for the forecasting of ground fog are—

(1) Mostly clear skies.

(2) Light winds, not more than 6 miles per hour at 8 p. m., but preferably not absolute calm.

(3) Thermal stability and early evening appearance of ground inversion.

(4) Sufficient absolute humidity, indicated by early evening deposit of dew.

Turning now to the local influences which must be especially considered in forecasting ground fog for any district, the most important of these are topography, the

presence of bodies of open water, and industrial regions as sources of atmospheric pollution. The influence of the local topography depends upon the tendency of radiation cooled surface air to collect in low lying places. This is responsible for the marked tendency of ground fog to form in low-lying places and the freedom of high locations from it. It also makes the formation of fog possible in absolute calm in the absence of all turbulence, due to the depth of the cold air. In flat country a certain amount of turbulence is necessary to carry the effect of ground cooling upward through a thicker layer than that for which the molecular diffusion of water vapor downward can prevent supersaturation by the deposit of dew.

The effect of local bodies of water in supplying heat and moisture to a radiation cooled air mass has been considered at some length under autumn early morning steam mists. As was pointed out there, this effect may be either to dissipate ground fog locally or to favor its formation, depending upon topography, temperature contrast between water and air, and the extent of the water surface. One phenomenon which may be closely related to a relatively warm damp underlying surface should be especially considered here. This is the very low ground fog which is especially characteristic of low-lying damp or swampy districts. It is such that two people coming toward each other through it may see each other's head and shoulders while the rest is concealed. It is rather frequent in certain localities in the southeastern United States as well as in Europe. The writer of this paper has not had the opportunity of observing such a fog, well marked, at first hand, nor does there appear to be any observational data such as to throw light on its nature. This would require merely a very few precise measurements of temperature of ground surface and of the overlying air mass through the first few meters and observations of the exact nature of the ground surface over which the formation occurs. However, in the absence of all such information, the following explanation of this low ground fog seems the most reasonable to be offered. In the first place, it is evidently a radiation fog, as it occurs only in clear calm weather. In the second place, the underlying ground surface must be warmer than the overlying air layer; otherwise, if Taylor's calculations are correct, supersaturation in the first 3 or 4 feet above the ground should be forestalled by molecular diffusion downward of the water vapor and its deposit as dew. Furthermore, the fact that the fog extends to just that height that molecular diffusion may be expected to extend in the course of one night, according to Taylor, seems to indicate that it is the result of evaporation from a slightly warmer underlying surface, in the complete absence of any dispersing turbulence. If this is the explanation, the air must have been cooled over a dryer or grass-covered radiation cooled surface, and settled over the warmer moist surface, or possibly due to its high moisture content has cooled by direct radiation. A moist earth surface cools very slowly by radiation, a grass cover very rapidly. At any rate, since the phenomenon seems to be due to molecular diffusion of vapor upward from the ground, the following conditions must hold for its formation:

(1) Absolute calm and thermal stability (no turbulence).

(2) A very high initial relative humidity in the lowest air layer.

(3) A small positive value of the difference $T_s - T_a$.

If now careful observation should show that this formation occurs over a moist surface such that $T_s - T_a < 0$, then not only a different explanation of this phenomenon must be found but also Taylor's quantitative computations and conclusions will be in part invalidated.

The local effect of a large industrial city, the result both of smoke obscurity and the production of hygroscopic nuclei of condensation, requires no detailed consideration here. In such a region the factors to be considered in forecasting are:

(1) Wind direction (whether it blows from or toward the source of pollution);

(2) Wind velocity (how far the impurities will be carried and how rapidly dispersed by turbulence);

(3) Vertical lapse rate (how rapidly the impurities will be dispersed upward); and

(4) Time of sunrise (effect of sunlight in increasing hygroscopic properties of nuclei).

The importance which this factor can attain is shown by a comparison of general visibilities prepared by Entwistle [46] for the aerodromes Croydon and Stag Lane near London. Croydon is southwest of London, Stag Lane north, and the contrasting visibilities with winds of different direction at these two stations is striking.

A complete and satisfactory mathematical solution of the problem of the forecasting of ground fog will probably never be possible, because of the great number of complicating factors. Calwagen made an attempt at such a general mathematical formulation of the conditions, but to get the thing in a practically workable form he had to make so many simplifying assumptions that the solution had no real significance. And even then he had completely passed over the very important locally variable conditions. An empirical method of attacking the problem has been suggested by G. I. Taylor. It is simply a graphical method of analyzing the past records of a particular station to try to find a definite relation between conditions and ground-fog formation such that the forecasting of fog is made routine. This method has the disadvantage that it can be applied only to a locality for which there exist records over a sufficient time to make the preliminary statistical analysis. But it has the advantage of being particular for each station, so that the local modifying influences are constant and are automatically expressed in the general relation obtained. The method as developed by Taylor has been tried out at a number of aerodromes in England with only a moderate degree of success. However, the method as applied by Taylor seems to be capable of further refinement. He simply takes for a given station all evenings on which the formation of ground fog seems possible (clear skies, light wind) and represents the conditions in a field of coordinates where the ordinates represent the difference between dry-bulb and wet-bulb temperature (or relative humidity, or vapor pressure) and the abscissae the current temperature at 8 o'clock. The conditions on each evening are represented by a point in the field, it being indicated whether fog formation followed later in the night or not. Taylor found that a smooth curve could be drawn through such a field of points so that nearly all the points above the curve represent conditions which were followed by nights free of fog. Below the line about half of the points represent conditions followed by fog formation, half not. Hence such a diagram sets off definitely for the locality to which it applies certain limits within which fog can not occur (too low humidity) and certain limits where it may definitely be expected. There is no reason why this method

[46] Meteorology in Relation to the Selection of Aerodrome Sites, pp. 4-5.

can not be extended further to include other factors than temperature and humidity. If wind direction and velocity and perhaps vertical temperature gradient were indicated also in the manner of entering the points on the diagram, other regularities might well appear in the distribution of the points representing fog formation, relative to the factors other than temperature and humidity, at each particular station. Of course, the relations found to hold at one station between the formation of fog and these general factors will not hold at another where the local influences may be quite different.

The dissipation of ground fog can almost always be forecast with certainty to occur before the middle of the morning. Ordinarily, in the open country, the later in the night it forms the less is its extent and density, and the sooner will it dissipate in the morning. Accordingly the dissipation may come at any time from sunrise till 10 or 11 o'clock. Only occasionally over big cities, as London or Hamburg, a real ground fog may persist through the whole day. In such a case the fog is probably more than 200 meters thick to begin with, and very dense. The influence which effects this density and persistence is the hygroscopic action of the nuclei of condensation, acted on by the sun's rays. This local influence of cities on the persistency of ground fog must always be considered in forecasting its dissipation.

An observation made by W. Georgii in the course of much night-flying experience on the western front during the war deserves special mention here. He remarks that the beam of a searchlight (such as those used at certain American airports to determine cloud elevations by night), if directed upward on a perfectly clear night, will show the first stages of the formation of a radiation fog hours before it may become visible to the unaided eye. Even when the air looks to be perfectly clear, the path of the beam of light observed from below appears as a whitish disk if the first stage of fog formation has begun. A systematic observation of this phenomenon might give information of practical value in forecasting radiation fog some hours in advance. How long in advance this disk becomes visible, and the significance of the clearness with which it stands out, are points which remain to be determined by regular observation. It may prove to be of no practical value whatsoever.

HIGH FOG

As has been pointed out, high fog formation takes place with the anticyclonic development occurring when the extensive mass of P. A. constituting a major cold outbreak becomes stagnant in late fall or winter over a continent. It was further shown that western and central Europe is the region especially favoring such developments, and that they do not occur in North America. Therefore, this discussion of high fog forecasting applies only to central and western Europe. The stagnation of a great P. A. mass over Europe means a blocking of the usual characteristic winter westerly air current over the continent which follows from the gradient between the normal semipermanent Icelandic Low to the north and ridge of high pressure over southern Europe which is a normal east-northeastward extension of the semipermanent Azores High. Hence the situations in which the typical high fog formation occurs, with the center of a very marked anticyclone over central Europe, is quite distinctive and not to be mistaken. From this it follows that the first two essentials in forecasting the formation of this fog are (1) the season of the year should be between October and March, inclusive; (2) the general circulation is stagnant, with an extensive anticyclonic development in air of polar origin over central and western Europe.

Now the formation of high fog does not follow with every such anticyclonic development. This depends on the properties of the air mass, to begin with, and the modifications of these properties in the resting mass. The most essential consideration for forecasting is that of the initial conditions in the mass, and these are a direct reflection of its past history. The significant difference is that between a P. A. mass which invades Europe from the NE., having passed overland over Prussia in its movement southward, and one which comes from due N. or NNW., having passed over the open sea. In the former case the air arrives cold and rather dry throughout. If high fog development occurs it is only very slowly after long subjection to the modifying influences, and it never reaches the density and extent that it does in the second case. When the P. A. mass has passed over the open sea in coming southward it is warmed at lower levels, hence the vertical gradient steepened, and the absolute humidity greatly increased, which renders very dense high fog development possible. The development of high fog may always be forecast in the case of the stagnation of such a P. A. mass. In the first case it should not be forecast unless it actually begins to make its appearance.

In the course of the development of the stagnant anticyclone the following important modifications of the air mass properties occur:

(1) Heating of the upper layers by the adiabatic compression resulting from the sinking and spreading of the air mass, and from the establishment of anticyclonic circulation. This results in the formation of a surface of subsidence.

(2) Cooling of the lower levels up to the surface of subsidence by direct radiation to space and by contact with the radiation cooled underlying surface. This results in the development of a marked inversion at the surface of subsidence.

(3) Gradual infusion of moisture (if the air mass is dry), smoke, and hygroscopic nuclei of condensation throughout the mass up to the inversion.

(4) A gradual weakening of the horizontal pressure gradient, and therefore a decrease of wind velocity at all levels.

Evidently enough, the air mass which has come overland and is cold and dry initially in the lower levels can only give fog after long continued action of the third factor. And this is most effective on the western side of the anticyclone, where the inversion is becoming progressively lower, and the air has moved farthest from its source over the continent, and is moving northward again after having passed farther south. From this follows the generally observed fact that high fog does usually occur first in the western portion of a dry central European anticyclone. The fact that high fog does not occur in the United States is a necessary consequence of the fact that all P. A. outbreaks are of the continental type, and that the general winter circulation over the United States is such that the third influence mentioned above does not have time enought to act, the stagnation is not sufficient.

In the air mass which has come over the open sea the cooling of the lower levels is aided by the direct radiation to space resulting from its great absolute humidity, and the tendency to reestablish a normal gradient, which seems to be about 0.6 the dry adiabatic up to the inversion. The fog formation occurs first at the base of the

inversion, probably because it is an active radiating surface, and grows downward. Therefore in the central regions of the anticyclone low stratus rather than surface fog should be forecast to begin with. In the peripheral portions it becomes progressively lower until it appears as surface fog. The formation begins almost as soon as the stagnation sets in, due to the high absolute humidity.

High fog reaches its greatest density at the base of the subsidence inversion, and may extend as a dense fog down to the ground. The condensation sometimes goes so far as to give light precipitation. It is very extensive, often covering a good part of western Europe, and is the highest type of fog. A normal height of such a fog at the center of the anticyclone, according to Georgii's observational data, seems to be about 1,000 to 1,200 meters, but in cases it extends to at least 1,700 meters. The fog frequently grows denser day after day, as long as the situation persists. But it frequently also shows some evidence of a daily period, being densest in the early morning. Such a fog may completely cripple all aviation lines over an extensive region for a period of weeks. Often, however, in flat country it is sufficiently high above the ground so that flying is feasible below the dense stratus. But in such a situation, visibility is always rather poor.

When such a fog is once well established, its dissipation is effected only by a displacement of the anticyclone and the stagnant air mass. Usually this is effected by a regeneration of the Icelandic LOW, and a reestablishment of the normal circulation with westerly current over Europe. Cloudless skies, dry air, and intense insolation above the subsidence inversion seem to have no perceptible effect in dissipating the fog. No doubt when the fog is once formed, reflection of the sunlight from its upper surface is an important factor in maintaining the inversion persistently.

INVERSION HAZE

Inversion haze, like the radiation fogs that are dependent on inversions, are of two types, according as the inversion is a ground inversion or a high inversion. But the forecasting of such haze is much easier than that of the fog, for the haze obscurity is directly proportional to the concentration of the smoke pollution, and not dependent on the attainment of any saturation concentration, as fog is, before it becomes visible.

In the forecasting of ground haze (ground inversion) the essential factor is the ground inversion. This inversion is that formed by the radiational cooling of the ground surface and lower air strata which occurs in the course of a single clear calm night, exactly as considered under ground fog. Other things being equal, the density of the haze is about proportional to the amount of the inversion. As has been pointed out, the occurrence of a ground inversion requires almost complete calm. Therefore, ground haze is very local in the region of the source of pollution. What wind drift there may be carries the haze with it, so that the expected direction and velocity of the wind must be considered in forecasting the haze distribution. This haze is of slight general significance, because it is so local, but for a particular aerodrome it may be of some consequence, for it may become quite dense, and is always low. In the case of ground fog formation, the haze is no longer detectable.

In the case of the high inversion haze the principal factor is the same high inversion which accompanies an extensive anticyclonic development, exactly as discussed under high fog. As soon as such an inversion becomes marked, and this happens invariably in the settling of a stagnant P. A. mass, the high inversion haze begins to appear in industrial regions. For this phenomenon the dryness of the air makes no difference, except as it may be obscured by fog, so the past history of the air mass has no significance. In general, the density of the haze is proportional to the amount of the inversion, and inversely to its elevation. Since this is a persistent phenomenon, the high inversion haze may gradually increase in extent and density day after day, until it becomes a general nuisance over a wide region. In forecasting the horizontal distribution of this more general haze, the primary factor to take into consideration is not the rather light wind in the lower air strata (below the base of the inversion) but the direction and velocity of the stronger winds in the upper portion of the inversion layer and the base of the layer above. As has been pointed out, it is probably in the upper portion of the inversion layer that the widespread horizontal distribution of high inversion haze takes place, and in this level that the rather clearly marked haze layer reaches its greatest density. This density will be greater if the wind here is light, but the haze will be more widespread if the winds are fresh. The upper level of the haze stratum is rather abrupt, just above the top of the inversion. Its elevation may be forecast accordingly. As has been mentioned, the obscuring effect of high inversion haze can not be judged by the observer on the ground. This effect appears much greater to the aviator above, often rendering the observation of landmarks on the ground, especially near large cities, quite impossible.

3. ADVECTION AND RADIATION FOG—MARITIME FOG

In the case of maritime fog advection is once more the essential condition for the fog formation, therefore the principal factors to be considered in forecasting this fog are again the modifying influences acting on the air mass as it advances. But the first thing to consider is the original properties of the air mass. Maritime fog develops in a M. P. A. mass or a M. Trans. A. mass in the course of its transformation to a C. Trans. A. mass over a cold land surface. Therefore it is to be forecast only as an inland fog, and only during the colder half of the year. Furthermore, it is to be forecast only upon the advance inland of M. P. A. or M. Trans. A. masses, which are characterized by high humidities at least up to the limits of shower convection, and the first by steep lapse rate at all levels, while the second is stable only in the lowest levels. This steep lapse rate and high humidity are essential to the fog formation. It also follows that as such an air mass moves inland the remnants of old fronts, the remaining convectional activity, and probably some orographical effects will cause considerable cloudiness and often intermittent rain. But this is no obstacle to the formation of maritime fog.

As soon as the air mass passes from over the warm open sea to the land surface, the supply of heat and moisture from below, which has maintained the steep lapse rate and convectional activity, ceases. There follows an immediate cooling of the lower level of the air mass, and a cessation of convection, as a result of the tendency to establish a normal equilibrium lapse rate. This is the important modification of the air mass properties that represents the change from M. P. A. to C. Trans. A., and which almost invariably results in a more or less dense fog. In favorable conditions (cold land surface, marked original M. P. A. properties in the air

mass) the fog can be expected within a very few hours of the movement inland of the air mass, if the winds are not too strong. Naturally it can not occur in regions which are closed to direct inundation by maritime air masses initially of polar origin, as in the United States between the Rockies and the Appalachians, where it never need be considered. In regions which are subject to this fog, it is one of the worst, because it is very frequent, quite dense and persistent, and usually of considerable horizontal extent. Furthermore, unless the conditions leading to its formation are thoroughly understood, its appearance is likely to be quite unexpected, because it comes suddenly and in a kind of situation in which no other fog occurs.

B. FRONTAL FOGS

As in the case of air mass fogs, the problem of forecasting a frontal fog resolves itself into two parts, namely, (1) to determine what fronts will pass over the region in question within the forecast period, and (2) to determine what their characteristics will be at the time of passage.

The problem of forecasting front movements, like air mass movements, is the general problem of weather forecasting for any element, and for that reason is given no special consideration here. Assuming that the future position of air mass and front is correctly forecast, to forecast frontal fogs it remains to consider in detail those properties of the fronts which are of significance for fog. However, the whole problem of the forecasting of the first appearance of a frontal fog becomes very complicated, for there are not only the same factors to be considered as for air mass fogs, but also the modifying influences of the fronts themselves, which are in turn variable. Therefore, unless the fog formation has already set in, the best rules to follow in the practical forecasting of these fogs are the empirical rules determined by actual experience, and applying to definite localities. When the fog has once made its appearance, the forecasting of the movement of the frontal fog zones is perfectly straightforward, according to the movement of the fronts themselves.

The properties of an air mass on which the formation of fog at any point depends, are always absolute humidity, temperature and lapse rate, and pressure gradient (wind velocity), whether it be air mass fog or frontal fog, except for the locally variable concentration of hygroscopic nuclei which plays no part in frontal fogs, on account of the absence of continued calm. These properties are subject to the same modifying influences in the case of frontal fog as in the case of air mass fog, but it is the modifying influences of the front which are essential. Therefore the relative importance of the various influences to be considered in forecasting frontal fogs is not the same as for air mass fogs. These differences are considered briefly for each air mass property:

(1) *Absolute humidity.*—The increase of humidity by evaporation from falling rain is the most important modification of this property in frontal fog formation, instead of evaporation from warm water surfaces. Drying by the deposit of dew becomes negligible.

(2) *Temperature and lapse rate.*—Due to the usual frontal cloudiness, the radiation process becomes relatively unimportant in effecting temperature or lapse rate changes. Also, the steady air movements prevent the marked cooling of surface air layers by conduction to a colder underlying surface. Finally the frequent active cyclogenesis which accompanies frontal activity makes cooling by adiabatic expansion a much more important influence affecting temperature distribution.

(3) *Horizontal pressure gradient.*—The marked cyclonic activity accompanying frontal fogs compared to air-mass fogs means that modifications of the pressure gradient, and therefore of air movements, may be both rapid and extensive.

There follows a very brief consideration of the forecasting of each kind of frontal fog in so far as it is possible in the light of these factors just considered.

1. PREFRONTAL FOGS

The prefrontal fogs as they appear on the chart are always distinguishable by their distribution in elongated zones directly preceding the front, and their abrupt cessation at the front. The nature of the front (warm, occluded, or cold) is an important point to note in the consideration of the fog.

PREFRONTAL FOG BEFORE A WARM FRONT

In the case when the fog formation has already occurred the forecasting of this fog is simply the comparatively simple problem of reckoning the front and fog zone displacement. The fog can be counted on to persist without any sudden dissipation. It is likely to increase in extent and density until the occlusion of the front, after which it begins gradually to diminish again. In the case of active cyclogenesis, the increase in the fog is likely to be rapid.

The forecasting of the first appearance of this prefrontal fog is a difficult problem. The two primary factors to be considered are the local pressure changes in the surface layers of the air mass in advance of the front, and the extent of the saturation of these same air layers by precipitation and the concomitant cooling by evaporation. The quantitative determination of the first of these factors is to be arrived at by a consideration of the instantaneous surface flow across isobars to lower pressure, the amount of fall due to the general deepening along the front, and the fall due to the displacement of the front. Quantitative computations of the local pressure change can readily be made on this basis for particular cases. It is readily shown that for a secondary development of not excessive intensity the 6-hour effect may be equivalent to a vertical displacement of 200 meters, or a cooling of 2° C. If the air in advance of the front has been saturated by copious warm front rain, this is quite sufficient to give a general fog formation. Thus it is possible for this type of fog to make an extensive appearance within six hours. But this is likely only in the rapid secondary formations, which are usually the result of the sudden development of a wave disturbance on a quasi-stationary front. Otherwise it is not necessary to reckon with such a possibility. Strong winds are unfavorable to the appearance of this fog, as of all others, but it may occur with moderate to fresh winds. For this reason it is rather more likely to occur inland in the winter, where the winds in advance of an active warm front are likely to be comparatively light.

The local orographical effect in causing low stratus formation in advance of a warm front by the forced ascent of the moist air mass is a distinct phenomenon. This will appear as a high fog on the windward side of exposed locations. The height at which this formation appears depends only upon the humidity of the prefrontal air mass, and therefore appears only after precipitation has occurred for some time, and at continually lower elevations.

The disappearance of prefrontal fog before a warm front takes place abruptly with the passage of the front. The fog zone itself moves farther, and disappears slowly

only after the occlusion of the front. This type of fog is often quite dense, while its vertical extent has not been specifically observed. But since it occurs under a lowering cloud deck and generally bad weather it makes flying quite impossible. It is not likely to persist longer than a few hours, preceding the front passage.

PREFRONTAL FOG BEFORE AN OCCLUDED FRONT

There is no difference whatsoever in principle between fog before a warm front and an occluded front. The occluded front is simply a later stage of the same thing, so that except in the rather unusual case of the regeneration of the front, there is no further development of the fog to be anticipated, only a gradual deterioration. Therefore, the forecasting of this fog depends only on forecasting the movement of the ready formed fog zone, as considered for the warm front case.

The development of a low stratus cloud deck by orographical influences may occur before an occluded front just the same as before a warm front. For either kind of front, a high coast line is especially favorable for the appearance of this phenomenon.

PREFRONTAL FOG BEFORE A COLD FRONT

Before a cold front the formation of fog is again due to the local pressure diminution, which within the warm sector is greatest here as a result of the prefrontal fall. In this case the prefrontal air mass is not saturated by prefrontal precipitation. But its humidity is high in the lowest levels because it is T. A. which has undergone the usual surface cooling resulting in a stable lapse rate and high relative humidity. If this process has already gone so far as to cause general T. A. fog, the prefrontal effect is simply to cause a local increase in density in the fog in a zone just in advance of the cold front. The properties of the T. A. must always be considered in forecasting prefrontal fog with a cold front, for if the air is not very nearly saturated to begin with, no fog formation will occur. This means that it is much less likely in summer than in winter, and less likely over the land than over the sea. Over the interior of continents in summer it is quite out of the question. In general, this fog is of little practical importance. It is of less density and extent than the fog before a warm front, except as the situation is such that the entire warm sector is foggy to begin with, in which case it is really a T. A. fog, the prefrontal factor being responsible only for local intensification. It is of short duration, for either the passage of the cold front or the occlusion of the warm sector end it abruptly.

2. FRONT PASSAGE FOGS (MIGRATING LOW CLOUD SYSTEMS)

The forecasting of the passage of migrating low cloud systems is simply a matter of the forecasting of the passage of fronts. They appear as real fogs at low elevations only in the exceptional case that the frontal cloud base rests on the ground.

FOG WITH A WARM FRONT

Except over continents in summer time the passage of a distinct warm front is always marked by the passage of a comparatively low thick cloud deck, which reaches its lowest elevation at the passage of the front. The problem of the forecaster, apart from timing the front passage, is simply to forecast the elevation of the cloud base. The best indication by which to judge this is that of accurate preceding observations of cloud elevations. Such moving cloud systems do not change their elevation rapidly. Theoretically this elevation can be reckoned directly from the temperature and humidity in the surface level of the T. A. current, it being simply the elevation at which saturation would occur upon the forced ascent of the air. In the limiting case that this elevation is zero, it becomes surface fog, but this is to be expected only over cold water surface or snow-covered land. Mountain ranges and high coast lines lower the effective elevation of the cloud base, both by the forced ascent of the preceding air mass and by turbulent mixing of the two air masses in the frontal zone. This tendency to a lowering of the cloud base above such obstacles is very important in aviation forecasting, for it is exactly here that it is necessary to be able to count on a certain clearance elevation below the cloud base. Finally, the passing of the front does not improve conditions much, for the low T. A. stratus and drizzle follow.

FOG WITH AN OCCLUDED FRONT

Forecasting the elevation of the base of the cloud system with an occluded front passage is exactly the same as with the warm front. But it should be remembered that with the occlusion of the warm sector the frontal condensation processes have reached their maximum, and that gradual improvement should follow.

This means specifically, with reference to the cloud system, that it will begin to decrease in density and the elevation of the base to increase. The unfavorable influence of certain orographical factors remain. It is no longer possible for the cloud base to rest on the ground as real surface fog, except at high elevations. The passage of the front is marked by the invasion of P. A. with the characteristic showers and clear air, instead of the typical low stratus and drizzle of the T. A. following a warm front passage. There may, over an inland region, follow maritime fog.

FOG WITH A COLD-FRONT PASSAGE

The forecasting of the cold front passage with attendant phenomena is the same as that of the other fronts. The typical cold front characteristics are those of the line squall, though usually they do not reach squall proportions, but are more in the nature of a shower with shift of wind. The cloud base is low, but never close to the ground except over high and exposed locations. The elevation of the cloud base can not be approximated from theoretical considerations, but can be estimated only on a basis of previous observations. Such passages are especially dangerous owing to the possibility of strong shifting winds and intense precipitation. These likewise are to be forecast only on the basis of previous observation, with especial attention to tendencies toward increasing or decreasing intensity of the phenomenon. Cold front passage disturbances are of short duration, rarely much more than an hour, and are quickly followed by the usual intermittent showers and broken skies of the P. A. mass. Maritime fog may follow a cold front passage over an inland region, but it need never be looked for immediately following a vigorously active front (strong shifting winds and shower).

3. POSTFRONTAL FOG AFTER A WARM FRONT

This fog is to be forecast on the same principle as a T. A. fog, for it is really T. A. fog intensified locally in the postfrontal zone. The principal factors effecting this local intensification are the coldness of the ground surface persisting from the prefrontal anticyclonic radiation cool-

ing and the mixing with remnants of the prefrontal cold air mass. It follows that with the advance of a T. A. current northward the first T. A. fog formation to be looked for and forecast is in this postfrontal zone. When once formed it will persist and move with the warm front until the complete occlusion of the T. A. current takes place. It is subject to the same seasonal limitations as T. A. fog, occurring over cold land surfaces in winter. It does not appear so markedly over water, because the post-frontal intensifying factors mentioned above are possible only in inland regions. In general, this zone of post-frontal fog represents the greatest density of fog possible in the T. A. current, so that gradually improving visibility may be expected to follow within a few hours, but not good visibility within the T. A. current.

PART IV

FOG AND HAZE DISTRIBUTION RELATIVE TO THE SELECTION OF AERODROME SITES

Any discussion of fog and haze bearing in the least on the aviation aspects of the problem would be incomplete without a few words on the selection of aerodrome sites. The rather great local variations in fog and haze frequencies make a consideration of this factor in the choice of an aerodrome site rather important. The most gen-general treatment of this subject which has appeared is contained in the paper of Captain Entwistle, Meteorology in Relation to the Selection of Aerodrome Sites, in which the principal elements considered are fog, haze, and low clouds. He goes from a statistical analysis of the records of these elements at the individual aerodromes in the British Isles to a statement, in terms of the position and local topography of the individual stations, of the underlying principles explaining his statistical results. Since the following discussion is intended to be both brief and perfectly general, it is based on the consideration of the conditions under which the principal fog forms are likely to occur, as set forth in the preceding parts of this paper, from which conclusions are drawn as to the nature of locations best suited for aerodrome sites.

In estimating the suitability of a given locality for an aerodrome site only those forms of fog need to be considered whose frequency or persistence over land is such that they may visibly affect statistical averages. The other forms are so scattered and incidental that they are of no practical importance. The fogs which it has been found may affect statistical averages over *land regions* are (1) monsoon fog, (2) radiation fogs, both ground fog and high fog, (3) inversion haze, (4) maritime fog, and (5) front passage fogs, which affect the fog frequencies on high exposed locations very greatly, while for lower locations they affect the low-ceiling frequency. The distinction between the fogs affecting coastal districts and those affecting inland districts is so pronounced that this distinction must be made at the beginning of the discussion.

In the selection of an aerodrome site in a coastal region, there are the general differences in fog frequencies between districts to be considered as well as the local differences within a limited area. Of the five fog types mentioned above the only ones characteristic of coastal regions are monsoon fog and front-passage fogs. As we have seen, there are certain coasts where monsoon fog is regularly present, and others where it is rather rare. In general, it is in the north temperate regions more frequent on west coasts than east, because there the normal eastward air movement brings it on shore more often. Furthermore, it is best developed in regions less frequented by cyclones. Front-passage fogs or migratory low cloud systems, on the other hand, are most frequent in regions of greatest cyclonic activity, but also on the exposed west coasts. Therefore, in general, an east coast is preferable to a west coast, and a southerly latitude to a northerly, except where the presence of particularly cold water off the coast favors monsoon fog. A high coast line is unfavorable, due to its effecting a forced ascent of inblowing air currents and condensation at low levels. This tendency toward a lowering of the effective cloud base with front-passage fogs has been considered more closely in the case of the warm front passage.

Of the local factors to be considered, the principal ones are the elevation of the site to be selected and its nearness to industrial regions with their pollution by smoke and hydroscopic gases. As far as this latter factor is concerned, the principal aim should be to get as far away from the source of pollution as possible, on the side toward which the wind is less likely to blow. In general, moderate winds are so much more prevalent on the coast than inland that a coastal site will enjoy comparative freedom from this source of annoyance. Likewise, when it comes to the radiation fogs, both high fog and ground fog, these are not formed to any extent along the coast, but are formed inland and may drift out to the sea at places. Therefore relatively high locations are favorable, because these fogs must advance over the low and sheltered sections.

On the other hand, an elevation greater than about 500 feet should not be chosen on an exposed coast, for the base of the rather frequent low front passage cloud systems are often not much more than that, while monsoon fog is usually appreciably deeper than that, so that it can not be escaped without being more than compensated for by low ceiling. At the same time that an exposed situation favors good visibility it has the disadvantage of being subject frequently to strong winds. In general, in a costal district, as far as visibility and ceiling are concerned, the most favorable location of an aerodrome site should be a rather high (not above 500 feet) and exposed field on a generally low coast as far removed from local industrial pollution as possible. From his statistical analysis of past records at the English aerodromes Captain Entwistle came to exactly the same conclusion.

For an inland district the problem is more complicated. There every type of fog mentioned above except monsoon fog may be prevalent. The more general phenomena, which are not greatly variable within a comparatively local district, are high fog and maritime fog. Those more dependent on local variations of topography, proximity of sources of atmospheric pollution, and possibly the nature of the ground surface, are ground fog, inversion haze, and low ceiling. Considering the more general phenomena first, it has been pointed out that high fog is characteristic only of very extensive inland continental regions that are open to the direct invasion of the great P. A. outbreaks which have moved across the open sea and where also stagnation of the general circulation may occur. Practically speaking, this means western and central Europe, where they are prevalent over all regions and not to be avoided. Maritime fog occurs in any inland region open to the invasion of air masses originally of polar origin which have become thoroughly maritime in character. This means any northerly or north temperate inland region which is not protected from the inflow of such air masses

by mountain barriers. Since the normal air flow is from the west, it also means that the western portions of large continents are most subject to them. Except as it is possible to locate an aerodrome in the lee of a range of mountains or high hills, which is always a good plan where practicable, it is not possible to avoid maritime fog locally.

An examination of the locally variable fog forms is of much greater significance in the choice of an inland aerodrome site. They merit careful individual consideration. As far as the front passage fogs are concerned, the elevation of the base of the migratory low cloud systems becomes higher with passage inland from the coast. Usually they appear as surface fogs only at very high elevations, except on the windward side of mountain ranges or rapidly rising ground with coastal exposure. As soon as there is a mountain range between the open sea and the inland region under consideration such cloud systems will rest only on the mountain tops. Thus the low ceiling caused by front passage cloud systems is comparatively unobstructive in inland regions, apart from mountainous districts. The occurrence of inversion haze depends always on the presence of industrial smoke pollution. The more general form of inversion haze, that which accompanies the high anticyclonic inversions, may become so widespread as not to be a local phenomenon. But there are always local variations in the density, which is greatest to the leeward of the smoke source. The inversion haze that goes with a ground inversion is always very local, likewise densest to the leeward of the source of pollution. A similar distribution of the hygroscopic nuclei of condensation has the result of frequently effecting a similar localization of the regions of greatest density in the formation of ground fog, or low radiation fog. By reason of the complete dependence of smoke haze, and partial dependence of ground fog on the location of the sources of pollution, this is probably the most important local factor affecting fog and haze frequency on a prospective inland aerodrome site. This is especially a fact because commercial aerodromes must usually be in the proximity of large industrial cities. When this is the case it is very important to consider the prevailing wind direction in the given locality, for when there is one general direction which is predominant this will be found to have a very considerable effect on local visibility frequencies. The amount to which visibility may be dependent on wind direction in the locality of a large city is very well shown by Entwistle's statistics for Stag Lone and Croydon, in the neighborhood of London.

Ground fog is really the most obstructive of the locally variable inland fogs. The effect of large cities on the distribution of this fog has just been considered. But in connection with this fog it is also necessary to consider local topography, the presence of bodies of water, and perhaps also the nature of the ground surface or the ground cover. Generally speaking, low-lying places are most favorably situated for the occurrence of ground fog, especially valleys which are suitably located to receive extensive cold-air drainage from surrounding highlands and which are more or less protected from/the normally prevailing winds. A difference in elevation of only a few hundred feet may make a very great difference in the frequency of ground fog in the same locality. Therefore, though it is always best from a consideration of low-ceiling and maritime fog for an aerodrome to be located in the lee of a mountain range, it is evident that the low-lying locations must be avoided. Situations lying high enough to insure good air drainage should always be selected.

As has been pointed out under autumn steam mists, bodies of water may have either the effect of local intensification or local dissipation of ground fog, depending on the topography. However, as a rule it is best to keep as far from them as possible in choosing an aerodrome site. This is certainly true for all lakes and rivers lying in well-marked valleys, suitably located for the drainage of radiation cooled air over the water surface. And even in flat country, though there is no doubt that extensive water surfaces affect local convection and ground fog dissipation immediately above them, it remains to be shown that the great supply of moisture to the air in this process does not intensify fog formation over the immediately surrounding land districts. It is here that the aerodrome must be located, not over the lake itself.

The effect of the ground surface or ground cover on the formation of ground fog may be important, but as yet it has not been investigated in the least. It may be effective both by the supply of moisture to the air and by the difference in radiation of heat to space from different kinds of surface. The difference in radiational cooling of a vegetation surface cover and moist soil has in the discussion of the very low ground fog been considered as a possible explanation of the phenomenon. Captain Entwistle considers the greater daily range of temperature which is characteristic of regions with a sandy soil to be favorable to the formation of ground fog. On the other hand, as Defant has found experimentally, low-humidity content of the air favors radiational cooling and insolational heating of a ground surface. If this factor enters into the greater daily range of temperature over a sandy soil, as seems quite probable, then the low humidity might well more than offset the greater daily temperature range in producing any radiation fog. All of these possibilities require further investigation before anything can be positively asserted.

These general considerations indicate that for an inland aerodrome site the most favorable location will be in the lee of a mountain range or at least of higher ground, at an elevation sufficient to insure good air drainage, and as far as possible from and to the windward of large industrial cities and inland bodies of water. No doubt there are many other factors to be considered in some localities. The suitability of any site as far as fog and haze are concerned can be judged only by a meteorologist thoroughly familiar with the underlying principles and so far as possible in the light of existing local records of these elements.

It remains to say a few words about the relative merits of coastal and inland sites for aerodromes. This, of course, depends entirely on the regions in question, and can be determined for a particular region only by a statistical analysis of the records of fog and haze. Captain Entwistle has shown that for the British Isles exposed coastal locations are preferable to inland locations. This is doubtless the result of the fact that the climate over the entire isles is maritime, and also that the aerodromes are for the greater part in southern England, where industrial smoke pollution is very great. Probably the same would be found to be true generally over western Europe, where the climate is also maritime and smoke pollution extensive. It has been pointed out repeatedly the great rôle played by a maritime climate (exposed to invasion by maritime air masses) in the formation of the worst inland fogs. The contrast has been made again and again between conditions in the

interior of the United States and western Europe. This is, briefly, merely the contrast between a continental and a maritime climate. Except for the Pacific coast, and to a lesser extent the most outlying points on the North Atlantic coast, the climate of the United States is prevailingly continental. Therefore in the United States, generally speaking, inland locations should be better suited for aerodrome sites, as far as fog, haze, and low ceiling are concerned, than coastal locations. Especially will this be true for the Pacific coast as compared with regions east of the Rockies. This is in accord with Köppen's figures of fog frequencies in the United States.

NOTES, ABSTRACTS, AND REVIEWS

Meteorological summary for Chile, October, 1928 (by J. Bustos Navarret, Observatorio del Salto, Santiago, Chile).—The characteristic features of the weather were weak intensity of atmospheric circulation and very light precipitation, even in the southern area.

Two important anticyclonic centers were charted—the first formed in the region of the Juan Fernandez Islands on the 5th, moved toward Chiloe on the 7th, and later remained stationary in the south for some time; the second forming in the same region as the first on the 20th, moved toward Chiloe and later, on the 25th, toward Argentina.

The depressions were of minor importance. Only three are worthy of mention, those of the 2d-3d and 12th-13th off the middle coast and that of the 16th-18th in the far south. The first depression was accompanied by cloudiness, fog, and mist; the second by the same conditions and in addition scattered rains in the south. The third disturbance, which crossed the extreme southern region, caused rains from Chiloe to Arauco; it brought the most marked change in weather during the month and was followed by frost in the central region of Chile.

Rarely has there been observed such weak atmospheric circulation as that characterizing this month. The total monthly precipitation at Valdivia, one of the rainiest points in Chile, was only 1.29 inches (normal 5.28 inches) and at Santiago only 0.10 inch.—*Translated by W. W. R.*

BIBLIOGRAPHY

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(NOTE.—Omitted this month but will be resumed in next issue.—*Ed.*)

SOLAR OBSERVATIONS

By HERBERT H. KIMBALL, Solar Radiation Investigations

SOLAR AND SKY RADIATION MEASUREMENTS DURING NOVEMBER, 1928

For a description of instruments and exposures and an account of the method of obtaining and reducing the measurements, the reader is referred to the REVIEW for January, 1924, **52**:42; January, 1925, **53**:29, and July, 1925, **53**:318.

Table 1 shows that solar radiation intensities averaged decidedly above normal values for November at Washington, D. C., and slightly above at Madison, Wis., and Lincoln, Nebr.

Table 2 shows that the total solar radiation received on a horizontal surface directly from the sun and diffusely from the sky was above the November normal at Washington, and decidedly below at Madison and Lincoln.

Skylight polarization measurements made at Washington on three days give a mean of 62 per cent, with a maximum of 67 per cent on the 5th. At Madison measurements made on two days give a mean of 75 per cent with a maximum of 76 per cent on the 6th. These are close to the corresponding average values for November at Washington and considerably above at Madison.

TABLE 1.—*Solar radiation intensities during November, 1928*

[Gram-calories per minute per square centimeter of normal surface]

Washington, D. C.

Date	Sun's zenith distance										
	8 a.m.	78.7°	75.7°	70.7°	60.0°	0.0°	60.0°	70.7°	75.7°	78.7°	Noon
	75th mer. time	Air mass A. M.					Air mass P. M.				Local mean solar time
	e.	5.0	4.0	3.0	2.0	[1] 1.0	2.0	3.0	4.0	5.0	e.
	mm.	cal.	cal.	cal.	cal.	cal.	cal.	cal.	cal.	cal.	mm.
Nov. 5	5.56				1.30	1.59	1.30	1.06	0.93	0.82	4.17
Nov. 6	5.56	0.72	0.85	0.99	1.18						5.79
Nov. 7	4.95				1.27						3.63
Nov. 8	9.14						1.09				8.48
Nov. 9	3.45					1.59	1.29				3.30
Nov. 14	4.75						1.28	1.10	0.92	0.83	4.95
Nov. 20	4.57			1.08	1.31		1.17				3.45
Nov. 22	3.81				1.32						3.00
Nov. 23	3.45	.96	1.08	1.19				1.11			3.00
Nov. 26	2.26		0.98	1.12							1.78
Means		(0.84)	0.97	1.10	1.28	(1.59)	1.23	1.09	(0.92)	(0.82)	
Departures		+.09	+.11	+.10	+.10	+.04	+.06	+.11	+.09	+.09	

[1] Extrapolated.

TABLE 1.—*Solar radiation intensities during November, 1928*—Con

[Gram-calories per minute per square centimeter of normal surface[

Madison, Wis.

Date	Sun's zenith distance										
	8 a.m.	78.7°	75.7°	70.7°	60.0°	0.0°	60.0°	70.7°	75.7°	78.7°	Noon
	75th mer. time	Air mass									Local mean solar time
		A. M.					P. M.				
	e.	5.0	4.0	3.0	2.0	[1] 1.0	2.0	3.0	4.0	5.0	e.
Nov. 3	5.56			1.14							4.37
Nov. 6	4.37	0.87	1.04	1.24	1.38	1.57		1.21			3.45
Nov. 15	7.04		1.00	1.11							6.76
Nov. 24	2.87	1.01	1.10	1.23							3.00
Nov. 26	2.06	0.85	0.98	1.12				1.13			2.62
Means		0.91	1.03	1.17	(1.38)	(1.57)		(1.17)			
Departures		+.02	+.01	+.02	+.08	+.04		+.01			

Lincoln, Nebr.

Date	8 a.m.	78.7°	75.7°	70.7°	60.0°	0.0°	60.0°	70.7°	75.7°	78.7°	Noon
Nov. 5	5.41	0.81	0.92	1.08	1.25	1.44		1.15	1.03	0.96	5.79
Nov. 6	4.57	0.83		1.03	1.31						5.36
Nov. 15	3.45							1.14	0.98		6.27
Nov. 20	2.74	0.91	1.08	1.25							3.30
Nov. 21	4.17		1.06								4.57
Nov. 22	3.00	1.13	1.22	1.33	1.46	1.61		1.30	1.21	1.10	2.87
Nov. 23	3.81			1.20	1.35	1.51					5.79
Nov. 24	3.00		1.18	1.30	1.44	1.60					2.36
Means		0.92	1.09	1.20	1.36	1.54		1.20	1.07	(1.03)	
Departures		−.01	+.05	+.01	+.01	−.02		+.01	+.02	+.09	

[1] Extrapolated.

TABLE 2.—*Solar and sky radiation received on a horizontal surface*

[Gram-calories per square centimeter of horizontal surface]

Week beginning—	Average daily radiation						Average daily departure from normal		
	Washington	Madison	Lincoln	Chicago	New York	Twin Falls	Washington	Madison	Lincoln
1928	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*
Oct. 29	266	169	146	122	127		+26	−15	−92
Nov. 5	258	122	242	106	144		+38	−43	+16
Nov. 12	211	114	156	91	109		+15	−24	−44
Nov. 17	182	137	246	91	96		0	+6	+44
Nov. 26	126	83	120	61	96		−27	−39	−64
Deficiency since first of year on Dec. 2							−1,465	−466	−1,843

POSITIONS AND AREAS OF SUN SPOTS

[Communicated by Capt. C. S. Freeman, Superintendent U. S. Naval Observatory. Data furnished by Naval Observatory, in cooperation with Harvard, Yerkes, and Mount Wilson Observatories. The differences of longitude are measured from central meridian, positive west. The north latitudes are plus. Areas are corrected for foreshortening and are expressed in millionths of sun's visible hemisphere. The total area, including spots and groups, is given for each day in the last column]

Date	Eastern standard civil time	Heliographic: Diff. long.	Heliographic: Longitude	Heliographic: Latitude	Area: Spot	Area: Group	Total area for each day
1928	*h. m.*	°	°	°			
Nov. 1 (Naval Observatory).	11 16	−53.0	301.0	+14.5	108		
		−35.5	318.5	+13.5	15		
		−19.0	335.0	+14.0		15	
		+16.0	10.0	−15.5	31		
		+56.0	50.0	−10.0	123		
		+62.5	56.5	+17.5		77	369
Nov. 2 (Naval Observatory).	13 15	−39.0	300.7	+14.5	93		
		−21.5	318.2	+13.5	15		
		−3.5	336.2	+13.5		31	
		+30.5	10.2	−15.5	15		
		+72.0	51.7	−10.0	123		
		+80.0	59.7	+17.0	62		339
Nov. 3 (Yerkes)	10 58	−71.6	256.2	+21.2		75	
		−71.2	256.6	−15.2		400	
		−26.7	301.1	+15.4		100	575
Nov. 3 (Naval Observatory).	11 39	−72.5	254.9	+21.5	62		
		−72.5	254.9	−16.5	370		
		−46.5	280.9	+8.0	31		
		−27.0	300.4	+14.5	93		
		+86.0	53.4	−10.0	185		74.

POSITIONS AND AREAS OF SUN SPOTS—Continued

Date	Eastern standard civil time	Heliographic: Diff. long.	Heliographic: Longitude	Heliographic: Latitude	Area: Spot	Area: Group	Total area for each day
1928	*h. m.*	°	°	°			
Nov. 4 (Yerkes)	10 38	−58.9	256.0	+21.0		75	
		−58.6	256.3	−15.5		375	
		−14.1	300.7	+15.0		175	625
Nov. 4 (Naval Observatory).	12 55	−75.0	238.5	−16.5		247	
		−58.5	255.0	+21.0	46		
		−58.5	255.0	−16.5	556		
		−31.5	282.0	+8.0	15		
		−13.0	300.5	+14.5	93		957
Nov. 5 (Yerkes)	11 34	−73.4	227.7	+13.0		250	
		−60.1	241.1	−16.1		250	
		−45.4	255.6	+21.0		100	
		−45.0	256.1	−16.0		350	
		−0.1	301.0	+15.1		125	1,075
Nov. 5 (Naval Observatory).	11 48	−74.0	227.0	+12.5	154		
		−60.5	240.5	−16.5		185	
		−46.0	255.0	+21.0	31		
		−46.0	255.0	−16.0	432		
		+0.5	301.5	+15.0		93	895
Nov. 6 (Naval Observatory).	11 38	−61.5	226.4	+12.5	201		
		−48.0	239.9	−16.5		154	
		−32.5	255.4	+21.0	31		
		−32.0	255.9	−16.5	463		
		+12.5	300.4	+15.0	93		942
Nov. 7 (Naval Observatory).	11 19	−48.5	226.4	+12.5	185		
		−34.5	240.4	−17.0		139	
		−20.0	254.9	+21.0	31		
		−19.5	255.4	−16.5	478		
		+26.0	300.9	+15.5	93		926
Nov. 8 (Naval Observatory).	11 28	−35.0	226.6	+12.5	170		
		−19.5	242.1	−17.0		154	
		−7.0	254.6	+21.0	31		
		−5.5	256.1	−16.5	478		
		+40.0	301.6	+16.5	93		926
Nov. 9 (Naval Observatory).	11 36	−22.0	226.3	+12.5	123		
		−7.5	240.8	−17.0		108	
		−7.0	241.3	+9.0		130	
		+6.0	254.3	+20.0	31		
		+8.0	256.3	−17.0	401		
		+34.0	282.3	+6.5		46	
		+53.0	301.3	+15.5	93		941
Nov. 10 (Naval Observatory).	13 40	−8.0	226.0	+12.5		154	
		+8.0	242.0	−17.0		93	
		+9.5	243.5	+9.0		293	
		+20.0	254.0	+20.5	15		
		+22.5	256.5	−16.5	432		
		+68.0	302.0	+16.0	77		1,064
Nov. 11 (Naval Observatory).	11 24	−85.0	137.1	+14.0		216	
		+4.0	226.1	+12.5		139	
		+20.5	242.6	−16.5		62	
		+21.5	243.6	+9.5		386	
		+32.0	254.1	+21.0	15		
		+35.0	257.1	−16.5	525		
		+80.0	302.1	+15.5	77		1,420
Nov. 12 (Naval Observatory).	11 24	−70.0	138.9	+14.0		154	
		+18.0	226.9	+12.5	108		
		+33.0	241.9	−16.5		93	
		+35.5	244.4	+9.5		417	
		+45.0	253.9	+21.0	15		
		+48.5	257.4	−16.5	463		1,250
Nov. 13 (Naval Observatory).	11 40	−70.5	125.1	−14.5	46		
		−58.0	137.6	+15.0		170	
		−29.5	166.1	−14.5		62	
		+30.5	226.1	+12.5		108	
		+50.0	245.6	+10.0		262	
		+58.5	254.1	+21.5	15		
		+62.0	257.6	−16.0	355		1,018
Nov. 13 (Yerkes)	12 3	−57.0	139.4	+15.7		190	
		+31.1	226.5	+13.2		200	
		+45.4	240.8	+9.6		100	
		+53.0	248.4	+9.7		100	
		+63.0	258.4	−15.7		625	1,215
Nov. 14 (Naval Observatory).	11 36	−50.0	123.4	−14.5		62	
		−44.5	137.9	+15.5		123	
		−36.5	145.9	−22.0	15		
		−15.0	167.4	−14.5		77	
		+43.5	225.9	+13.5		77	
		+60.0	242.4	−16.5	15		
		+62.5	244.9	+9.5		216	
		+76.5	258.9	−16.0	247		832
Nov. 14 (Yerkes)	12 53	−44.3	137.4	+16.6		150	
		−12.9	168.8	−14.6		75	
		+44.9	226.7	+13.5		125	
		+66.8	248.5	+9.4		150	
		+78.7	260.2	−15.4		500	1,000
Nov. 15 (Naval Observatory).	11 38	−45.5	123.7	−14.0	46		
		−31.5	137.7	+15.0		139	
		0.0	169.2	−16.5		139	
		+6.5	175.7	+11.5	31		
		+57.5	226.7	+12.5	31		
		+79.5	248.7	+10.0	247		633

POSITIONS AND AREAS OF SUN SPOTS—Continued

Date	Eastern standard civil time	Heliographic: Diff. long.	Heliographic: Longitude	Heliographic: Latitude	Area: Spot	Area: Group	Total area for each day
1928	h. m.	°	°	°			
Nov. 16 (Naval Observatory).	12 37	−31.0	124.5	−14.0	31		
		−18.0	137.5	+15.5		123	
		+14.5	170.0	−16.0		170	
		+19.0	174.5	+12.0		185	
		+70.5	226.0	+12.5	15		524
Nov. 17 (Naval Observatory).	11 32	−17.0	125.9	−15.5		46	
		−5.5	137.4	+16.0		93	
		+28.0	170.9	−16.5		139	
		+33.0	175.9	+12.5		185	463
Nov. 18 (Naval Observatory).	11 44	−70.0	59.6	+17.5	15		
		−63.0	66.6	−13.5		31	
		−5.0	124.6	−14.0		31	
		+7.5	137.1	+15.0		93	
		+42.0	171.6	−17.5	93		
		+44.5	174.1	+11.5		185	448
Nov. 19 (Naval Observatory).	11 30	−57.5	59.1	+17.5	15		
		−48.5	68.1	−13.5		62	
		+9.5	126.1	−14.5	15		
		+21.0	137.6	+15.5		77	
		+55.5	172.1	−17.5	108		
		+59.0	175.6	+11.0		93	370
Nov. 20 (Naval Observatory).	11 42	−44.5	58.8	+18.0	15		
		−34.0	69.3	−13.0		31	
		+34.0	137.3	+15.0	62		
		+68.0	171.3	−18.0	108		
		+73.0	176.3	+11.0		93	309
Nov. 21 (Naval Observatory).	11 35	−32.0	58.1	+18.0	15		
		−20.5	69.6	−12.5		31	
		+46.5	136.6	+15.0	62		
		+80.0	170.1	+12.0	62		
		+85.0	175.1	−17.5	108		278
Nov. 22 (Naval Observatory).	11 33	−53.5	23.5	+18.5	15		
		−16.0	61.0	+15.5		31	
		−4.0	73.0	−12.5	15		
		+34.0	111.0	+16.5	15		
		+60.5	137.5	+15.0	77		153
Nov. 23 (Naval Observatory).	11 57	−42.5	21.1	+19.5		77	
		+1.0	64.6	+15.5	9		
		+46.5	110.1	+16.5	6		
		+73.5	137.1	+15.0	93		185
Nov. 25 (Naval Observatory).	12 16	(1)	(1)	(1)	(1)	(1)	
Nov. 26 (Yerkes)	11 22	(1)	(1)	(1)	(1)	(1)	
Nov. 26 (Naval Observatory).	11 51	−15.0	9.1	+14.0	9		
		+39.5	63.6	+15.5	3		
		+55.0	79.1	+22.5		46	58
Nov. 27 (Naval Observatory).	13 49	−80.5	289.3	+13.5	46		
		+29.5	39.3	−14.0		62	
		+69.5	79.3	+22.5		154	262
Nov. 28 (Naval Observatory).	11 24	−68.0	290.0	+13.5	31		
		+41.0	39.0	−14.5	15		
		+84.0	82.0	+22.5		216	262
Nov. 29 (Harvard)	11 43	−56.0	344.5	+3.5	21		21
Nov. 30 (Mount Wilson)	12 00	−82.0	228.4	+11.0	19		
		−75.0	235.4	−16.0	99		
		−65.0	245.4	+8.0		238	
		−41.0	269.4	+13.0		7	
		−30.0	280.4	+8.0	2		365
Mean daily area for November							584

[1] No spots.

PROVISIONAL SUN SPOT RELATIVE NUMBERS FOR NOVEMBER, 1928

[Data furnished by Prof. W. Brunner, University of Zurich, Switzerland]

November, 1928	Relative numbers	November, 1928	Relative numbers	November, 1928	Relative numbers
1	53	11	84	21	37
2	47	12		22	28
3	49	13	101	23	
4		14	73	24	16
5	60	15	77	25	
6	70	16		26	29
7	66	17	49	27	
8	53	18	52	28	
9		19	58	29	8
10		20	38	30	28

Number of observations, 21; mean, 51.2.

AEROLOGICAL OBSERVATIONS

By L. T. SAMUELS

Table 1 shows that the mean free-air temperatures for the month were above normal at the northern stations and below normal at the southern stations, the departures being mostly of moderate magnitude. Relative humidity departures show no unusual features. Those for vapor pressure agree, in general, with those for temperature with the exception of Broken Arrow and the upper levels at Ellendale where the relationship is inverse, i. e., negative temperature departures occurring with positive vapor pressure departures and vice versa. Resultant winds for the month were not far from normal. (See Table 2.)

A strikingly large rise in the free-air temperature from the 20th to 21st is shown by kite records made at Broken Arrow on the morning of these days and by an airplane observation made at a nearby airport on the afternoon of the 20th. Although the afternoon surface temperature rose 10° C. higher on the 21st than on the 20th, the records show that this increase began in the higher levels several hours sooner than at the surface. The morning kite record of the 20th indicates a rapid warming taking place in the upper levels at that time. At the 2,500-meter level the temperature rose 1.5° C. in less than 1 hour, 8.3° C. in 7 hours, and 19.5° C. in 26 hours. During this entire period the upper winds were from the northwest, but evidently their trajectories differed considerably. On the morning of the 20th the air at all levels observed was plainly under the influence of an extensive high-pressure area, but by the 21st the upper winds, although of the same direction as on the 20th, were blowing out of a large low-pressure area which was moving eastward across the northern part of the country. Such large temperature changes in the free air during so short a period are rarely observed.

An unusually strong wind (50 m. p. s. WNW) was observed at Sheridan, Wyo., at an altitude of 4,800 meters on the afternoon of the 5th. Pressure was very low at the time to the north of Sheridan and this depression moved rapidly eastward during the ensuing 24 hours. It is also noted that a high-pressure area prevailing to the westward was entirely displaced by a cyclonic disturbance by the next morning.

TABLE 1.—*Free-air temperatures, relative humidities, and vapor pressures during November, 1928*

TEMPERATURE (°C.)

Altitude m. s. l.	Broken Arrow, Okla. (233 meters) Mean	Departure from normal	Due West, S. C. (217 meters) Mean	Departure from normal	Ellendale, N. Dak. (444 meters) Mean	Departure from normal	Groesbeck, Tex. (141 meters) Mean	Departure from normal	Royal Center, Ind. (225 meters) Mean	Departure from normal	Washington, D. C. (7 meters)[1] Mean	Departure from normal
Meters												
Surface	9.3	−0.4	11.0	0.0	−0.5	+1.8	10.9	−2.3	5.4	+0.7	7.4	+0.1
250	9.2	−0.4	10.9	+0.1			10.9	−2.1	5.3	+0.8	6.5	0.0
500	7.8	−0.8	10.6	+0.6	−0.3	+2.0	10.3	−2.1	4.0	+0.9	6.2	−0.2
750	6.7	−1.1	9.9	+0.8	0.8	+2.9	9.3	−2.4	3.0	+0.8	5.6	−0.3
1,000	6.1	−1.2	8.9	+0.7	1.1	+3.0	9.1	−2.1	2.2	+0.6	4.3	−0.5
1,250	5.9	−0.9	8.0	+0.6	0.7	+2.6	8.7	−1.7	1.5	+0.5	2.7	−0.8
1,500	5.5	−0.7	7.1	+0.6	−0.4	+1.8	8.3	−1.3	0.5	+0.1	1.3	−1.4
2,000	4.2	−0.3	6.0	+1.2	−2.4	+1.4	6.7	−1.0	−1.3	+0.1	0.0	−1.9
2,500	2.0	−0.3	4.5	+1.4	−4.7	+1.3	4.0	−1.6	−2.8	+0.5	−1.6	−1.4
3,000	−0.3	−0.2	2.1	+1.2	−7.1	+1.5	2.1	−1.1	−4.7	+0.9	−4.3	−1.6
3,500	−2.3	+0.2	−0.2	+1.5	−9.6	+1.7	1.0	+0.4	−7.3	+0.3	−8.0	−2.5
4,000	−5.1	−0.1	−3.8	+0.6	−12.6	+1.6	−1.6	+0.6	−10.8	−0.5		
4,500	−8.7	−1.0	−7.8	+0.2	−15.2	+2.0			−13.0	−0.1		
5,000			−9.0	+1.3								

RELATIVE HUMIDITY (%)

Altitude m. s. l.	Broken Arrow Mean	Departure	Due West Mean	Departure	Ellendale Mean	Departure	Groesbeck Mean	Departure	Royal Center Mean	Departure	Washington Mean	Departure
Surface	69	+2	69	0	76	−2	76	+2	74	+1	65	−7
250	69	+2	67	−1			73	+1	74	+1	63	−7
500	68	+4	61	−3	73	−3	70	+3	71	−1	58	−7
750	68	+6	58	−4	62	−8	68	+5	70	0	56	−6
1,000	64	+5	57	−4	55	−10	59	0	67	0	58	−4
1,250	59	+4	55	−4	50	−11	49	−6	64	+1	62	−2
1,500	55	+3	54	−3	49	−9	45	−7	63	+4	64	+1
2,000	47	0	46	−5	45	−10	40	−6	57	+3	59	+5
2,500	44	+1	39	−4	43	−11	38	−2	60	+10	52	+3
3,000	37	−5	37	−3	40	−14	35	−1	54	+5	35	−5
3,500	31	−8	34	−4	34	−20	31	−4	54	+7	53	+13
4,000	31	−4	34	+3	33	−23	30	−3	54	+9		
4,500	31	−1	32	−3	33	−26			54	+9		

VAPOR PRESSURE (mb.)

Altitude m. s. l.	Broken Arrow Mean	Departure	Due West Mean	Departure	Ellendale Mean	Departure	Groesbeck Mean	Departure	Royal Center Mean	Departure	Washington Mean	Departure
Surface	8.51	+0.29	9.63	+0.14	4.54	+0.30	11.08	−0.95	7.13	+0.53	7.14	−0.74
250	8.47	+0.31	9.45	+0.12			10.68	−0.90	6.93	+0.41	6.50	−0.80
500	7.70	+0.30	8.42	+0.04	4.47	+0.31	9.70	−0.83	6.06	+0.22	5.94	−0.90
750	7.02	+0.23	7.71	0.00	4.06	+0.21	8.75	−0.75	5.51	+0.17	5.52	−0.81
1,000	6.38	+0.15	7.05	−0.05	3.65	+0.09	7.56	−0.95	4.93	+0.11	5.26	−0.63
1,250	5.74	+0.08	6.51	+0.14	3.21	−0.10	6.25	−1.24	4.42	+0.14	5.03	−0.51
1,500	5.19	+0.14	5.92	+0.29	2.92	−0.16	5.45	−1.12	4.05	+0.24	4.68	−0.47
2,000	4.07	+0.15	4.70	+0.43	2.33	−0.28	4.28	−0.61	3.52	+0.48	3.72	−0.31
2,500	3.40	+0.35	3.50	+0.47	1.90	−0.31	3.44	−0.36	3.54	+1.07	2.97	−0.14
3,000	2.56	+0.10	2.98	+0.65	1.46	−0.35	2.97	+0.21	2.98	+0.82	1.04	−0.79
3,500	1.95	+0.09	2.40	+0.61	0.95	−0.50	2.69	+0.58	2.71	+0.94	1.87	+0.64
4,000	1.86	+0.52	1.28	+0.39	0.60	−0.58	2.64	+1.09	2.67	+1.41		
4,500	1.76	+0.77	0.44	−0.22	0.20	−0.81			2.63	+1.65		

[1] Naval air station.

TABLE 2.—*Free-air resultant winds (m. p. s.) during November, 1928*

Altitude m. s. l.	Broken Arrow, Okla. (233 meters) Mean Direction	Mean Velocity	Normal Direction	Normal Velocity	Due West, S. C. (217 meters) Mean Direction	Mean Velocity	Normal Direction	Normal Velocity	Ellendale, N. Dak. (444 meters) Mean Direction	Mean Velocity	Normal Direction	Normal Velocity
Meters	°		°		°		°		°		°	
Surface	S. 71 W.	1.4	S. 45 W.	1.6	S. 77 W.	1.0	W.	0.6	N. 61 W.	2.9	N. 50 W.	2.5
250	S. 66 W.	1.5	S. 45 W.	1.6	S. 70 W.	1.1	S. 82 W.	0.7				
500	S. 54 W.	2.0	S. 40 W.	2.3	S. 64 W.	2.2	S. 79 W.	1.6	N. 59 W.	3.1	N. 59 W.	2.7
750	S. 53 W.	3.0	S. 42 W.	3.2	S. 75 W.	3.0	S. 85 W.	2.4	N. 52 W.	4.7	N. 58 W.	4.1
1,000	S 72 W.	3 2	S 54 W.	4 0	S 87 W.	3.8	S. 85 W.	3.2	N. 56 W.	5.3	N. 61 W.	5.0
1,250	S. 79 W.	3.7	S. 64 W.	4.8	N. 80 W.	4.8	S. 88 W.	4.6	N. 54 W.	5.1	N. 64 W.	5.8
1,500	N. 88 W.	4.6	S. 74 W.	5.6	N. 77 W.	5.5	W.	5.6	N. 46 W.	6.1	N. 62 W.	6.9
2,000	N. 87 W.	6.3	S. 80 W.	7.0	N. 68 W.	7.1	N. 89 W.	7.4	N. 54 W.	6.3	N. 63 W.	8.6
2,500	N. 89 W.	7.0	S. 85 W.	7.8	N. 65 W.	9.3	N. 88 W.	8.9	N. 54 W.	7.4	N. 63 W.	10.8
3,000	N. 75 W.	6.0	S. 87 W.	8.6	N. 75 W.	9.7	S. 84 W.	9.8	N. 58 W.	8.2	N. 66 W.	12.8
3,500	N. 75 W.	6.6	S. 88 W.	9.2	N. 87 W.	14.0	S. 81 W.	12.0	N. 74 W.	11.4	N. 68 W.	13.9
4,000	N. 46 W.	9.2	S. 88 W.	10.2	S. 61 W.	13.0	S. 79 W.	13.8	N. 59 W.	12.5	N. 68 W.	13.6
4,500	N. 54 W.	8.9	N. 80 W.	10.2	W.	12.0	S. 83 W.	14.6	N. 68 W.	14.7	N. 64 W.	16.0
5,000					W.	12.0	N. 86 W.	13.9				

Altitude m. s. l.	Groesbeck, Tex. (141 meters) Mean Direction	Mean Velocity	Normal Direction	Normal Velocity	Royal Center, Ind. (225 meters) Mean Direction	Mean Velocity	Normal Direction	Normal Velocity	Washington, D. C. (34 meters) Mean Direction	Mean Velocity	Normal Direction	Normal Velocity
Meters	°		°		°		°		°		°	
Surface	N. 80 W.	0.2	S.	0.3	S. 60 W.	3.4	S. 50 W.	2.3	S. 84 W.	1.1	N. 59 W.	1.3
250	S. 43 W.	0.4	S. 27 W.	0.9	S. 58 W.	3.4	S. 52 W.	3.1	N. 83 W.	5.1	N. 78 W.	3.7
500	S. 22 W.	1.0	S. 5 W.	2.1	S. 66 W.	6.1	S. 57 W.	5.4	N. 76 W.	7.5	N. 69 W.	5.8
750	S. 50 W.	1.0	S. 23 W.	2.8	S. 71 W.	7 8	S 62 W.	7 0	N 76 W.	8 1	N 65 W.	6 9
1,000	S. 61 W.	1.8	S. 38 W.	3.4	S. 75 W.	8.9	S. 69 W.	7.7	N. 57 W.	9.2	N. 64 W.	7.3
1,250	S. 53 W.	2.6	S. 51 W.	4.0	S. 79 W.	9.2	S. 73 W.	7.9				
1,500	S. 59 W.	3.8	S. 61 W.	4.5	W.	8.9	S. 78 W.	9.0	N. 55 W.	10.8	N. 61 W.	8.2
2,000	S. 69 W.	4.7	S. 75 W.	5.5	N. 75 W.	9.0	S. 85 W.	10.1	N. 81 W.	9.9	N. 72 W.	9.8
2,500	N. 89 W.	5.7	S. 81 W.	6.9	N. 72 W.	11.6	S. 88 W.	11.9	S. 71 W.	12.5	N. 89 W.	10.7
3,000	W.	9.8	S. 84 W.	8.8	N. 74 W.	14.0	N. 85 W.	13.3	N. 89 W.	11.3	N. 81 W.	14.4
3,500	S. 76 W.	9.6	S. 75 W.	10.6	N. 74 W.	12.4	N. 84 W.	13.3	S. 77 W.	12.8	N. 82 W.	13.8
4,000	S. 22 W.	5.0	S. 72 W.	8.8	N. 74 W.	19.1	N. 87 W.	13.9	N. 68 W.	12.0	N. 75 W.	14.8
4,500	S. 22 W.	4.0	S. 70 W.	10.6	N. 45 W.	16.0	N. 88 W.	13.7	N. 68 W.	14.0	N. 78 W.	18.4
5,000					N. 45 W.	16.0	N. 75 W.	14.6	N. 68 W.	15.0	N. 73 W.	17.0

WEATHER IN THE UNITED STATES

THE WEATHER ELEMENTS

By P. C. DAY

GENERAL CONDITIONS

The leading feature of November weather in 1928 was the heavy precipitation, especially about the middle of the month, over the central portions of the country. The mildness of October preceding continued over considerable areas in November, but the region of most notable temperature excess in November was the north-central portion.

PRESSURE AND WINDS

At the beginning of November a low-pressure center covered the southern plains, with rain and snow falling over a considerable area, especially to the northwestward of the center. This storm advanced in a northeasterly course, reaching central Quebec by the 4th, after causing large falls, principally rain, over much of the central and southern plains and the central valleys, also a few areas farther east. As this proceeded eastward a well-marked area of high pressure crossed the country, moving southeastward, bringing low temperatures to most central districts and to the east Gulf region.

Another storm, from the 5th to the 9th, crossed the country not far from the parallel of 40° latitude, but the precipitation connected with it was mostly of little account. On the 10th a storm of small consequence was noted east of the Florida Peninsula, but this developed rapidly as it moved northeastward, the center on the morning of the 11th being at a considerable distance east of the Middle Atlantic coast.

Just before the middle of the month a storm from the central Plateau region advanced eastward and then northeastward to the vicinity of Lake Superior, with mainly moderate precipitation. This was immediately followed by a more important storm which crossed the north Pacific coast early on the 14th and traveled rapidly to the Texas Panhandle by the morning of the 16th. Thence the storm turned northeastward to the Lake region, accompanied by heavy falls of snow or rain over the southern Plains, the central valleys, and the southwestern part of the Lake region, Kansas City measuring 6.42 inches of rain within 48 hours on the 15–17th.

Still another storm moved northeastward between the 18th and the 20th from Alabama to the Gulf of St. Lawrence, causing widespread, but mainly moderate precipitation in most districts east of the Mississippi River, snow falling in the northern and eastern portions of the Ohio drainage area and to the northward.

The first days of the final decade brought further precipitation to northeastern districts, but fair weather prevailed elsewhere. On the 24th a marked area of high pressure, moving southeastward from the Canadian Northwest, reached the northern Plains, whence it advanced to the South Atlantic States by the 27th, bringing the lowest temperature marks of the month to nearly all central and eastern stations.

The last few days of the month saw the movement of a well-marked storm from the middle Plateau to the Texas Panhandle and thence to the Lake region with considerable precipitation over most Central and Southern States and over the Lake region and the Northeast.

In the far West the chief precipitation period was the 8th to 15th, but the northern portions received amounts of less importance during the first four days of the month and again during the final few days.

The average sea-level pressure for the month was above normal in most portions, especially in the Rocky Mountain, Plains, and Gulf States. The pressure averaged less than normal in New England and most of the Lake region and Middle Atlantic States.

The general distribution of the average pressure and the variations from the means of the preceding month, also the prevailing directions of the winds are shown on the charts which follow. Details of severe wind and other storms appear in the table at the end of this section.

TEMPERATURE

The first week of November was generally cooler than normal, except in the northeastern and far western States. The temperatures were abnormally low for the season between the Mississippi River and the Rocky Mountains, where they averaged from 2° to 13° below the normal, while in the far West they were generally from 1° to 5° above and from Virginia northward from 1° to 2° above. In the East the freezing line extended to southwestern Virginia and in the West to Oklahoma and northwestern Texas, while in the Mississippi Valley it did not extend as far south as St. Louis.

During the second week the weather was moderately cool generally east of the Mississippi River, except in the upper Lake region, and it was abnormally warm for the season from the upper Lake region to central Texas and to the westward. In the Great Plains and central and northern Rocky Mountain States, temperatures averaged from 3° to 10° above the normal. In most eastern States they were from 1° to 4° below the normal, while light frosts occurred as far south as northern Florida. However, temperatures below freezing were not reported farther south than southern Virginia and the mountains of North Carolina. West of the Mississippi River they extended only to southern Iowa, the southwestern portion of Kansas, and the Panhandle of Texas.

The third week was unusually warm east of the Rocky Mountains and much below the average over the Great Basin and far Southwest. Temperatures were abnormally high for the season in the Ohio Valley, lake region, and North Atlantic States, where they averaged from 6° to 15° above the normal, while in the Mississippi and Missouri Valleys they were from 2° to 11° above. On the other hand, in much of the Great Basin, Arizona, and New Mexico they averaged from 3° to 6° below. In the East the freezing line extended to western North Carolina, while west of the Mississippi River it extended to central Arkansas and southwestern Texas.

The last week was unusually cold for the season east of the Mississippi River and in much of the Southwest, but was abnormally warm in the Northwestern States. It was unseasonably cold from Virginia, West Virginia, and Kentucky southward, the mean temperatures ranging from 4° to 12° below normal; on the other hand, in the northern Great Plains they averaged from 4° to 12° above, while west of the Rocky Mountains they were generally a little above the normal.

The month as a whole was mild. It was abnormally warm from the upper Lake region to the northern Great Plains, where the temperatures averaged from 3° to 6° above the normal. It was likewise from 2° to 4° above in southern New England, the Middle Atlantic States, and the lower Lake region. From the Ohio Valley to the Great Plains and southward, and also from the Rocky Mountains westward, the temperatures for the month ranged from 1° or 2° above to 1° or 2° below the normal.

As a whole, the month was warmer than normal, with temperatures 90° or above at a few points in Arizona, California, Florida, and Texas. On the other hand, subzero temperatures were recorded at many places in the Rocky Mountain, Great Basin, and most northern border States, chiefly during the latter half of the month.

PRECIPITATION

The precipitation for the month was very unevenly distributed over the United States. Most of the lake region and Ohio Valley received more than the normal amount, while heavy to excessive falls, ranging in some cases from four to six times the normal, were received in parts of the southern Great Plains and lower Missouri Valley; the greatest November fall of record being measured at Kansas City and St. Joseph, Mo., Keokuk, Iowa, and Milwaukee, Wis. On the other hand, in the South the amounts were below the normal, except in the southern portions of Louisiana and Texas, where they were somewhat above, as also they were in most of California. Throughout the interior of the Atlantic States, the northwestern portion of the Great Plains, the northern Rocky Mountain region, and from the central portion of the Great Basin westward, except most of California, the precipitation was markedly deficient, many sections receiving less than 25 per cent of the normal, while in portions of the northwestern Great Plains and of southwestern Arizona no precipitation whatever was received.

SNOWFALL

No heavy snows occurred in the northern border States, but in the western mountains rather heavy falls were received in Colorado and portions of Nebraska, Wyoming, Utah, and New Mexico, and also in the eastern portion of California, while in portions of the Texas Panhandle unusually heavy falls for the season occurred about the middle of the month.

But little snow remained on the ground at the end of the month, except in the mountains of the West, the upper lake region, and northern portions of the New England States.

RELATIVE HUMIDITY

Over all interior and most western portions of the country the relative humidity was above the normal for the month, the values over the central Great Plains and Rocky Mountain regions being particularly high. Over the Atlantic and East Gulf States the average relative humidity was mainly less than normal and similar conditions prevailed along the immediate Pacific coast.

SEVERE LOCAL STORMS, NOVEMBER, 1928

[The table herewith contains such data as have been received concerning severe local storms that occurred during the month. A more complete statement will appear in the Annual Report of the Chief of Bureau]

Place	Date	Time	Width of path, yards	Loss of life	Value of property destroyed	Character of storm	Remarks	Authority
Floyd County, Iowa (Rock Grove Township).	14	4 p. m.			$2,000	Tornado	Character of damage not reported	Official, U. S. Weather Bureau.
Vinton, Benton County, to Silver Creek, Delaware County, Iowa.	14	4:30-5:15 p. m.		1	200,000	do	Scores of farmsteads demolished or damaged; much livestock killed; trees and telephone poles leveled; 9 injured.	Official, U. S. Weather Bureau; the Journal (Sioux City, Iowa).
Chester, Iowa	14	5:30 p. m.			3,000	do	Several buildings damaged; 2 persons injured	Official, U. S. Weather Bureau.
Wisconsin (eastern and southeastern).	14-15				10,000	High winds	Damage chiefly to overhead-wire systems, small farm buildings, windows, etc.	Do.
Orlando, Okla	15	7 p. m.	220	2	10,000	Tornado	Several homes and barns wrecked; path 2 miles	Do.
Michigan (Thumb district)	15			1	25,000	Heavy gales	Farm buildings blown down; orchards uprooted	Do.
Iowa (central and northeastern).	17					Snow and sleet	Overhead wires broken; poles snapped off; trees damaged.	Do.
Cumberland County, Pa	19	2:30 p. m.				Wind	Considerable property damage reported	Do.
Chemung, Tioga, and Broome Counties, N. Y.	19	4-5 p. m.			120,000	do	Houses and barns unroofed; several barns demolished; livestock killed; heavy damage to manufacturing plant.	Do.
Wilkes-Barre, Pa., and vicinity.	19	4:30 p. m.			500,000	Probably tornado	Heavy damage to buildings, trees, etc	Do.
Montour and Columbia Counties, Pa.	19	P. m.				Wind	Scores of homes unroofed; communication cut off; highways blocked.	Do.
Rutland, Vt	19	do				do	Wire communication interrupted; 2 automobiles demolished; poles blown down.	Daily News (Burlington, Vt.).

RIVERS AND FLOODS

By H. C. FRANKENFIELD

On the evening of November 15, 1928, a disturbance of apparent North Pacific origin was central over New Mexico. For the ensuing 36 hours it moved northeastward, and during this period it was attended by excessive rains over eastern Kansas, Missouri, eastern Iowa and northern Illinois, and the southern upper Lake region. Floods were, of course, inevitable, especially in the rivers of eastern Kansas and Missouri. They were especially severe in the Osage, Cottonwood, and Neosho Rivers of Kansas, and the following description thereof was prepared by Mr. S. D. Flora, meteorologist in charge of the Weather Bureau office at Topeka, Kans.:

Disastrous floods occurred along the Marais des Cygnes (Osage), Cottonwood, and Neosho Rivers as the result of downpours of 7 to 10 inches of rain that began during the night of November 15-16 and lasted approximately 36 hours. Such heavy rains were without precedent in Kansas so late in the year.

The total property damage in the basins of the three rivers was estimated at $1,948,000. Eight lives were lost—six in Franklin County, one in Miami County, and one in Labette County.

The greatest damage occurred in and near Ottawa, where the Marais des Cygnes reached a record breaking stage of 37.6 feet 13.6 feet above bankful, at 2 p. m. of the 17th. Fifty blocks of the city were covered by the flood waters. Seven hundred buildings were damaged, 30 houses washed away, and 40 others washed from their foundations. The municipal power plant and waterworks pumping plant were entirely disabled, leaving the city in darkness for several nights and without drinking water. Altogether, the water reached approximately 150 acres of land within the city limits. The damage in the city, exclusive to railways, was estimated at $200,000 by representatives of the United States Engineer Corps. On the same authority the total damage in Franklin County, of which Ottawa is the county seat, was estimated at $750,000, with an additional $200,000 damage to railways in and near Ottawa. Damage in Miami County was estimated at $400,000.

Damage to other counties in the basins of the three rivers was fairly well distributed and was mostly to bridges, highways, and

matured crops. Ottawa was the only city of considerable size that was seriously affected, though Quenemo and Burlington were heavy losers. Railway traffic was either entirely interrupted or seriously hampered for several days along the Neosho and Marais des Cygnes Rivers and a considerable amount of trackage washed out. Main highways were badly flooded in many places, making automobile travel impossible where the floods were highest.

Warnings for these floods were issued first on the morning of November 16, and frequently thereafter until the waters began to subside. Savings as a result of these warnings were reported as $130,000.

Crest stages and dates are given in the table at the end of this report.

The flood at the same time in the valley of the Walnut River, a small tributary of the Arkansas River, was relatively even more disastrous. The rainfall ranged from about 3.5 to 10.3 inches during the 36 hours and the waters soon overflowed the banks of the small stream. The flood came with great rapidity, one man in Winfield, Kans., reporting a rise in the river of about 5 feet in 23 minutes, while the river gage showed a rise from 8.4 feet at 5 p. m., November 16, to 40.1 feet at midnight of November 17–18, a total rise of 31.7 feet in 31 hours. Two square miles of the city of Winfield were covered, in some places to a depth exceeding 10 feet. Hundreds of families were rendered homeless temporarily, but suffering during the cold weather following was averted by the prompt action of the Red Cross and the local authorities.

Warnings of the floods were issued as soon as possible, but, owing to the rapidity of movement of the flood wave, the losses were heavy, about $965,000, of which $591,500 was in tangible property and $271,950 in crops. Of the entire loss, about $420,000 fell upon the city of Winfield. Savings accomplished through warnings were reported as $150,000.

In the Verdigris River at Independence, Kans., there was a crest stage of 43.5 feet, 13.5 feet above the flood stage, on November 19, but flood stages were not quite reached in the lower Verdigris and lower Neosho Rivers. Nevertheless, warnings were very helpful to bridge constructors and engineering and sand and gravel companies. Losses as reported amounted to $160,000 in Kansas, with 25,000 acres of land overflowed Crop losses were $43,000, and those of railroad and other real property $102,000. In Oklahoma the amount reached only about $25,000, with about 1,000 acres of land overflowed. Savings to sand and gravel companies through the warnings were about $25,000.

The Blue River, a small stream which passes through the extreme eastern portions of the city of Kansas City, Mo., also experienced a severe flood that drove 161 families from their homes and more or less covered a district about 12 miles in length from Swope Park to the junction of the Blue with the Missouri River. The flood was the greatest of record, reaching, on the morning of July 17, 47.5 feet above "normal" (probably low water) near the Seventy-first Street Bridge in Swope Park. This was 10 feet above the high-water marks of 1906 and 1927. No warnings were possible, and losses to business houses and homes amounted to $167,000.

The rainfall responsible for this flood amounted at Kansas City to 6.42 inches in about 33 hours.

Floods in the Osage and Grand Rivers of Missouri were forecast at the proper time, but, owing to the comparative frequence of floods during the present season, there was no damage to crops and none of much consequence to other industries.

There was also a moderate flood in the lower Missouri River and the Mississippi River from the Hannibal, Mo., district southward to Cape Girardeau, Mo., but apparently there was no damage except in the Hannibal district. The smaller rivers of northeastern Missouri were the highest within the memory of the oldest inhabitant, and the waters of the Fabius River caused a breach in the levee of the Marion County drainage district with the resulting overflow of about 4,000 acres of rich farm lands. There were also a few smaller breaks in the Lima Lake district of Illinois on the opposite side of the Mississippi River. No damage of consequence was done along the Mississippi River, except in the unprotected bottom lands and behind the levees mentioned above. Much shocked corn was carried away and standing corn was bent over and ruined. Crop losses amounted to $25,000, and other property losses, mainly to railroads, about $21,000. Reported value of property saved through the flood warnings, $50,000.

By the time the flood-producing rains of November 16–17 had ceased another storm from the West had reached Texas, and soon another heavy one-day rain period covered the southern Appalachian region, especially the mountain regions of southeastern Kentucky, the total rainfall ranging from about 2 to about 6 inches. The smaller streams, including the South Fork of the Kentucky River, were soon in severe flood, as was also the Cumberland River in Kentucky, and considerable damage was done. The losses along the South Fork of the Kentucky River and its tributaries were $70,100, of which $55,000 was in prospective crops.

Along the Cumberland River three lives were lost, and property damage and loss amounted to $186,500, of which $25,500 was in matured crops and $155,200 in tangible property.

River and station	Flood stage	Above flood stages—dates		Crest	
		From—	To—	Stage	Date
MISSISSIPPI DRAINAGE	Feet			Feet	
Cumberland: Williamsburg, Ky	22	20	22	22.6	Nov. 20
New: New River, Tenn	25	19	19	26.5	19.
Elk: Fayetteville, Tenn	14	19	21	18.3	19.
Mississippi:					
Quincy, Ill	14	18	22	17.5	19.
Hannibal, Mo	13	18	23	17.9	19.
Louisiana, Mo	12	18	24	17.3	20.
Grafton, Ill	18	21	24	19.8	23.
Alton, Ill	21	20	25	24.0	23.
Chester, Ill	27	22	25	27.9	24.
Cape Girardeau, Mo	30	22	26	31.5	24.
Illinois:					
Peru, Ill	14	18	(2)	15.9	20.
Pearl, Ill	12	22	26	13.2	24.
Missouri:					
Boonville, Mo	21	19	22	23.5	20.
St. Charles, Mo	25	20	25	27.75	22.
Grand:					
Gallatin, Mo	20	2	5	31.0	4.
		17	21	35.5	19.
Chillicothe, Mo	18	2	7	27.8	6.
		17	22	30.7	19.
Brunswick, Mo	12	17	24	18.0	21.
Thompsons Fork: Trenton, Mo	20	17	19	22.4	18.
Osage:					
Quenemo, Kans	30			[3] 38.3	17.
Ottawa, Kans	24			37.6	17.
Osceola, Mo	20	22	30	27.5	25.
Warsaw, Mo	22	20	29	28.1	24.
Tuscumbia, Mo	25	24	29	27.0	27.
Neosho:					
Neosho Rapids, Kans	22	17		27.3	18.
Le Roy, Kans	24	17	22	28.0	19.
Iola, Kans	15	17	23	21.0	20.
Chanute, Kans	20			28.3	21.
Parsons, Kans	22			27.5	24.
Oswego, Kans	17	19	28	25.3	24.
Cottonwood:					
Elmdale, Kans	32			34.2	17.
Emporia, Kans	20			27.0	17.
Verdigris: Independence, Kans	30	17	21	43.5	19.
Black: Corning, Ark	11	19	22	11.5	20.
WEST GULF DRAINAGE					
Guadalupe: Victoria, Tex	16	7	7	16.1	7.

[1] Continued from last month. [2] Continued at end of month. [3] Estimated.

MEAN LAKE LEVELS DURING NOVEMBER, 1928

By UNITED STATES LAKE SURVEY

[Detroit, Mich., December 3, 1928]

The following data are reported in the Notice to Mariners of the above date:

Data	Lakes [1]			
	Superior	Michigan and Huron	Erie	Ontario
Mean level during November, 1928:	*Feet*	*Feet*	*Feet*	*Feet*
Above mean sea level at New York	603.39	580.61	571.73	245.67
Above or below—				
Mean stage of October, 1928	−0.16	+0.16	−0.13	−0.09
Mean stage of November, 1927	+0.87	+1.71	+0.64	+0.82
Average stage for November, last 10 years	+1.32	+1.25	+0.28	+0.57
Highest recorded November stage	−0.12	−2.31	−1.94	−2.15
Lowest recorded November stage	+2.33	+2.93	+1.28	+2.26
Average departure (since 1860) of the November level from the October level	−0.16	−0.26	−0.26	−0.23

[1] Lake St. Clair's level: In November, 1928, 574.98 feet.

EFFECT OF WEATHER ON CROPS AND FARMING OPERATIONS, NOVEMBER, 1928

By J. B. KINCER

General summary.—During the first decade generous rains in the Southwestern States materially improved the condition of the soil in that area and benefited ranges and pastures, as well as truck crops in the more southern districts. Additional moisture in the central Rocky Mountain area was also helpful, but the cold wave that overspread the Great Plains States was detrimental to outside operations, while there was some damage to down corn by mud and heavy snow in parts of the upper Mississippi Valley. Light to heavy frost extended southward to the northern parts of the east Gulf States, while in the Middle West a hard freeze overspread northwestern Texas; very little harm was done.

Heavy to excessive rains in parts of the interior valleys and the southern Plains States during the second decade were generally unfavorable for agricultural interests, especially for gathering corn, with local damage from floods, the latter principally in eastern Kansas. Elsewhere the period was generally favorable for outdoor operations, especially over the eastern third of the country. In the Western States the abrupt change to colder was rather hard on livestock, but the storms were not severe, as a rule, and no materially damaging low temperatures occurred.

During the last decade the unseasonably cold weather in the more Southeastern States, which brought freezing temperatures to the Gulf coast and heavy frost well southward over the Florida peninsula, resulted in damage to tender vegetation—such as beans, peppers, and eggplants—southward to the Okeechobee district in Florida, while some tender truck crops were nipped farther north; little harm resulted to the hardier varieties. Except in the Northeast, the weather was generally favorable for outdoor operations and seasonal farm work made good advance. Moisture was needed in the South Atlantic and east Gulf sections, but otherwise the soil was well supplied. There was but little snow cover at the close of the month, while the mild weather in the western mountain districts resulted in considerable melting of the previous deposit.

Small grains.—During the first decade growth of winter wheat was materially retarded by cold weather over much of the principal producing area, but moisture was mostly abundant and conditions continued satisfactory. Showers were helpful in the Ohio Valley and additional rain or snow in the Southwest favored fall-sown grains, but in the far Northwest moisture was still insufficient. During the second decade precipitation in the Pacific Coast States and Rocky Mountain districts was favorable for winter wheat, while further showers were helpful in parts of the East, although all fall grains needed moisture in the Southeast. There was some local damage by flooding in the lower Missouri and upper Mississippi Valleys, but conditions continued mostly favorable in the main winter wheat belt. During the last decade cool weather retarded growth of winter wheat in the eastern part of the belt, but elsewhere satisfactory advance continued, with the soil in excellent shape generally. Conditions were less favorable in the Pacific Northwest, where moisture was needed, and it was rather dry for winter grains in the Southeast and some adjoining sections.

Corn.—During the first decade corn husking made good advance in the Ohio Valley, except for some interruption by rains, while in Iowa heavy rains or snows on the first of the month stopped work, with some damage to down corn from snow and mud. Husking was retarded also in the Great Plains, but elsewhere this work made good advance. During the second decade frequent rains caused interruption to housing, especially in the Mississippi Valley and southern Great Plains; there was some damage by flooding, while high winds blew down more corn in Iowa and leveled shocks in the western Lake region. In the northern Great Plains, the upper Ohio Valley, and generally in the Atlantic Coast States, conditions were mostly favorable and husking made good advance. During the last decade much better weather for gathering corn prevailed and in Iowa conditions were very favorable for husking, though soft fields caused some delay. Housing the corn crop was well along, or about completed, at the close of the month, except in parts of the Mississippi Valley.

Cotton.—During the first decade the weather was mostly favorable for outside operations in the eastern part of the belt, and picking the remaining crop made satisfactory advance in most sections. There was some delay by rain in Arkansas, and in Oklahoma conditions were unfavorable for picking, while in northwestern Texas growth was stopped by killing frost. During the second decade scrapping made good advance east of the Mississippi River, but over the northwestern portion conditions were decidedly unfavorable. In Arkansas frequent rains delayed harvest and little progress was made in northern Texas, while in Oklahoma staple was damaged by heavy rains, with picking suspended. During the last decade picking the remaining crop made rather slow advance in the more western and northwestern portions of the belt, because of cool weather and wet fields. In Arkansas conditions were favorable and picking made good progress, with considerable still to gather in some sections; east of the Mississippi River harvest has been nearly completed.

Miscellaneous crops.—Pastures were in fair to good condition, for the season, in most sections east of the Mississippi River and ranges were still affording some feed in the northern Great Plains during the month. The range continued partly open in the northern Rocky

Mountain area, but in the Great Basin the dry autumn was unfavorable for feed, and precipitation was generally needed. Livestock continued in satisfactory condition throughout the month, except for some suffering from cold locally.

Winter truck progressed well until the last decade when there was some injury by frost, especially in Florida; some frost damage was reported in California. There was some injury by frost to cane buds and eyes in Louisiana during the last decade, but seed cane was mostly saved, while excellent harvest weather prevailed generally. Citrus were beginning to need rain at the close of the month in Florida; elsewhere conditions were satisfactory generally.

WEATHER OF THE ATLANTIC AND PACIFIC OCEANS

NORTH ATLANTIC OCEAN

By F. A. YOUNG

November was another stormy month over the North Atlantic, and the number of days with gales was equal to or above the normal over the greater part of the steamer lanes and also over the region west of the sixtieth meridian, north of the Bermudas.

The outstanding feature of the weather of the month was the series of exceptionally severe storms that ravaged the coast of Europe, and was, according to press reports, responsible for large loss of life and great damage to property.

Due to the great interest shown in the flight of the German airship *Graf Zeppelin*, Charts VIII to XI were drawn to cover the period from October 29 to November 1, the ship leaving the United States on the former date on her return trip to Germany. The weather conditions during the voyage from Germany were shown on the October Charts VIII to XII, covering the 11th to 15th.

The number of days with fog was somewhat below normal over the Grand Banks and off the European coast and about normal off the American coast and over the eastern section of the steamer lanes.

TABLE 1.—*Averages, departures, and extremes of atmospheric pressure at sea level, 8 a. m. (seventy-fifth meridian), North Atlantic Ocean, November, 1928*

Stations	Average pressure	Departure [1]	Highest	Date	Lowest	Date
	Inches	*Inch*	*Inches*		*Inches*	
Julianehaab, Greenland	29.51	([2])	29.92	26th	28.18	21st.
Belle Isle, Newfoundland	29.64	−0.24	30.18	12th [3]	28.26	8th.
Halifax, Nova Scotia	29.91	−0.00	30.34	2d	29.36	7th.[3]
Nantucket	29.99	−0.10	30.40	1st	29.62	23d.
Hatteras	30.13	+0.01	30.56	15th	29.72	8th.
Key West	30.08	+0.05	30.28	23d	29.84	4th.
New Orleans	30.20	+0.09	30.52	26th	29.90	7th.
Cape Gracias, Nicaragua	29.89	−0.01	29.96	23d [3]	29.82	4th.
Turks Island	30.04	+0.03	30.16	28th	29.88	17th.
Bermuda	30.20	+0.12	30.54	15th	29.88	11th.
Horta, Azores	30.24	+0.14	30.64	24th	29.72	18th.
Lerwick, Shetland Islands	29.52	−0.18	30.26	1st	28.57	16th.
Valencia, Ireland	29.79	−0.10	30.52	30th	28.96	16th.
London	29.78	−0.16	30.33	29th	28.93	16th.

[1] From normals shown on Hydrographic Office Pilot Chart, based on observations at Greenwich mean noon, or at 7 a. m., seventy-fifth meridian time.

[2] No normal available.

[3] And on other dates.

During the first five days of the month favorable weather prevailed generally, with the exception of a moderate gale on the 5th, central off the south coast of Newfoundland, and on the same day northerly winds of force 9 were reported from near 55° N., 25° W.

From the 6th to 11th moderate to strong gales prevailed over the greater part of the steamer lanes, and on the 11th there was also a LOW in the vicinity of Hatteras which was accompanied by winds of hurricane force. On the 12th the center of the LOW was near Halifax, while southwest gales also occurred off the west coast of Ireland.

From the 13th to 15th the middle and eastern sections of the steamer lanes were again swept by westerly to southwesterly gales. On the 15th a norther of force 7 to 8 was reported near Turks Island.

From the 15th to 17th a disturbance was off the coast of Europe; it reached its greatest extent and intensity on the 16th, when westerly winds of hurricane force prevailed over a region extending as far west as the twenty-fifth meridian.

On the 19th two areas of low pressure over the middle and northeastern sections of the ocean were responsible for heavy weather over a large area. By the 20th the storm area had contracted somewhat and extended from the Azores to the English Channel. On the same date there was a moderate disturbance in the vicinity of Newfoundland.

From the 21st to 26th Europe was visited by the last and most protracted storm of the month. Reports from vessels and land stations indicated westerly winds of force 8 to 12 over a comparatively large area during the greater part of this period.

On the 26th Belle Isle reported wind NNW., force 9, with snow, while on that date and on the 27th moderate gales were encountered in the region between the Bermudas and Newfoundland. On the 27th land stations and vessels in the vicinity of the south coast of England reported southwesterly winds of force 7 to 8.

On the 28th a fairly well developed disturbance of limited extent was central near 40° N., 45° W.; this moved slowly north-northeastward, and on the 29th the center was near 47° N., 40° W., and, as shown in table of gale reports, winds of hurricane force were encountered near the center.

OCEAN GALES AND STORMS, NOVEMBER, 1928

Vessel	Voyage From—	Voyage To—	Position at time of lowest barometer Latitude	Position at time of lowest barometer Longitude	Gale began	Time of lowest barometer	Gale ended	Lowest barometer	Direction of wind when gale began	Direction and force of wind at time of lowest barometer	Direction of wind when gale ended	Highest force of wind and direction	Shifts of wind near time of lowest barometer
NORTH ATLANTIC OCEAN			° ′	° ′				Inches					
Conte Grande, Ital. S. S.	Gibraltar	New York	38 16 N.	56 18 W.	Nov. 7	7 p., 7	Nov. 7	29.65	WNW	WNW., 10	WNW	WNW., 10	Steady.
Galtymore, Br. S. S.	Tyne	Galveston	37 49 N.	39 25 W.	7	8 p., 7	7	29.41	SW	—, 5	SW	W., 9	SW.-NW.-SW.
El Dia, Am. S. S.	New York	do	31 50 N.	76 10 W.	8	5 a., 8	8	29.64	S	S., 8	NW	SW., 9	S.-SW.-W.
Challenger, Am. M. S.	Avonmouth	Baltimore	39 21 N.	57 45 W.	9	8 a., 9	9	29.18	SW	SW., 8	NW	WSW., 11	SW.-W.-NW.
Maine, Dan. S. S.	South Shields	Boston	51 52 N.	42 58 W.	8	11 a., 9	9	28 89	WSW	WSW., 10	W	W., 11	WSW.-W.
Medina, Am. S. S.	New York	Mobile	33 20 N.	78 00 W.	10	3 p., 10	10	29.50	W	ENE., 6	NNW	N., 12	ENE.-N.
City of Alton, Am. S. S.	Rotterdam	New York	48 33 N.	41 12 W.	9	1 p., 10	11	28.57	SW	WSW., 10	NW	W., 12	SW.-WSW.
Tulsa, Am. S. S.	Glasgow	Charleston	32 30 N.	71 30 W.	11	7 a., 11	11	29.58	S	S	NW	NW., 12	S.-W.
City of Flint, Am. S. S.	Dundee	Philadelphia	58 00 N.	25 00 W.	11	—, 11	13	28.61	WSW	WSW	WNW	—, 10	Var.
Steel Seafarer, Am. S. S.	Port Said	New York	38 56 N.	51 31 W.	12	6 p., 12	13	29.45	SSE	SSW	W	S., 12	S.-SSW.
Thuringia, Ger. S. S.	Cobh	do	49 00 N.	30 00 W.	13	7 p., 13	16	29.33	W	SSE., 8	NW	WNW., 11	SSE.-SW.
Dresden, Ger. S. S.	do	do	48 03 N.	35 10 W.	14	4 p., 14	14	29.31	WSW	WSW., 8	W	WSW., 11	WSW.-W.
De Grasse, Fr. S. S.	Havre	do	49 44 N.	5 16 W.	15	—, 15	16	29.57	SSW	WSW	W	WSW., 11	SSW.-W.
Steel Voyager, Am. S. S.	Avonmouth	Mobile	49 10 N.	9 00 W.	16	4 a., 16	17	28.92	WSW	WSW., 8	WSW	WSW., 12	Steady.
Bird City, Am. S. S.	New York	Copenhagen	56 45 N.	27 45 W.	18	8 p., 18	20	29.76	NNW	NNW., 10	NW	WNW., 12	NNW.-WNW.
Sylvafield, Br. M. S.	Tyne	Canal Zone	45 42 N.	33 08 W.	19	4 p., 19	20		NW	NW., 10	WZW	NW., 11	SE.-NE.-NW.
Berk, Du. S. S.	Archangel	Providence	54 55 N.	49 10 W.	20	Noon, 20	21	28.29	SE	WSW., 10	NW	WNW., 11	SE.-SW.
Steel Voyager, Am. S. S.	Avonmouth	Mobile	43 19 N.	21 23 W.	19	Noon, 20	21	29.26	S	SW., 10	W	SW., 12	Steady.
Deer Lodge, Am. S. S.	Rotterdam	Galveston	46 27 N.	13 04 W.	20	6 p., 20	21	29.64	SSW	S., 7	WNW	SW., 11	
West Celeron, Am. S. S.	London	New Orleans	47 30 N.	14 10 W.	21	4 a., 21	24	29.54	SSW	SSW	NW	—, 10	SSW.-SW.
El Occidente, Am. S. S.	New York	Galveston	35 00 N.	75 18 W.	22	7 p., 22	24	29.91	NW	NW., 6	N	NW., 9	Steady.
Bird City, Am. S. S.	do	Copenhagen	57 55 N.	7 00 E.	23	6 p., 23	25	28.75	S	S., 10	S	SSE., 12	SE.-SSE.
Pres. Roosevelt, Am. S. S.	Cobh	New York	51 04 N.	16 42 W.	24	2 a., 24	25	29.76	WSW	WNW., 10	NW	W., 11	W.-NW.
Liberty Land, Am. S. S.	Gibraltar	do	36 40 N.	59 20 W.	25	10 a., 26	28	29.46	SW	WNW., 8	NW	NW., 10	W.-NW.
McKeesport, Am. S. S.	Havre	do	35 20 N.	50 00 W.	28	4 a., 28	28	29.84	SW	WSW., 8	NNW	WNW., 10	WSW.-NNW.
München, Ger. S. S.	Cobh	do	48 06 N.	43 36 W.	29	10 a., 29	29	28.78	N	NW., 12	W	NW., 12	NW.-W.
NORTH PACIFIC OCEAN													
Golden Tide, Am. S. S.	Hong Kong	San Francisco	41 39 N.	145 15 W.	Oct. 31	6 p., 1	Nov. 3	28.20	SE	SE., 9	NW	SW., 9	SSW.-W.
Yayoi Maru, Jap. S. S.	Miike	Grays Harbor	49 33 N.	158 33 W.	30	6 a., 2	4	28.48	SSE	W., 6	WSW	SSW., 10	2 pts.
West Montop, Am. S. S.	Seattle	Philadelphia	40 02 N.	124 00 W.	Nov. 1	10 a., 2	2		SE	SE., 9	SSW	SE., 9	SE.-SW.
Yuri Maru, Jap. S. S.	Muroran	Vancouver	49 40 N.	145 43 W.	1	8 p., 1	3	27.82	ESE	SSW., 6	SW	W., 11	SW.-S.-SSE.
Pres. Madison, Am. S. S.	Yokohama	Seattle	49 51 N.	141 36 W.	1	2 a., 3	3	28.41	NW	SE., 9	SW	WSW., 11	SSE.-W.
Hoyeisan Maru, Jap. S. S.	do	San Francisco	47 38 N.	175 18 W.	1	4 p., 2	4	29.45	WNW	W., 10	SSW	W., 10	WNW.-NW.
Wisconsin, Am. S. S.	Orient	do	47 50 N.	165 59 W.	2	5 a., 2	4	28.64	W	W., 10	SW	SW., 11	W.-SW.
Kaga Maru, Jap. S. S.	Victoria	Yokohama	43 05 N.	151 17 E.	3	11 p., 3	4	29.19	W	W., 7	N	WNW., 10	3 pts.
Taiyo Maru, Jap. S. S.	Yokohama	San Francisco	23 44 N.	162 06 W.	3	4 p., 4	4	30.20	NE	NE., 8	NE	NE., 9	Steady.
New York, Am. S. S.	Portland	Yokohama	45 37 N.	161 51 E.	3	2 p., 4	5	29.02	SSW	WNW., 12	WNW	WNW., 12	WSW.-WNW.
City of Vancouver, Br. S. S.	Grays Harbor	Osaka	53 16 N.	159 49 W.	2	2 p., 3	12	27.95	W	S., 3	WNW	WNW., 10	S.-WNW.
General Smuts, Br. S. S.	Everett	Sydney	44 00 N.	124 30 W.	8	4 p., 8	9	29.94	S	S., 10	SW	S., 10	S.-SW.
Makiki, Am. S. S.	Port Allen	Puget Sound	40 41 N.	138 40 W.	9	7 p., 10	11	29.30	SW	WSW., 9	WSW	WSW., 9	Steady.
Arkansas, Fr. S. S.	Seattle	San Francisco	44 45 N.	124 39 W.	9	1 p., 11	12	29.37	SSE	S., 10	S	S., 11	Do.
Wairuna, Br. S. S.	Fanning Island	Vancouver	38 07 N.	134 03 W.	13	8 p., 13	14	29.82	WNW	WNW., 9	WNW	WNW., 9	Do.
Taibu Maru, Jap. S. S.	Miike	Port Townsend	39 20 N.	148 05 E.	14	2 p., 14	14	29.80	S	S., 9	WSW	S., 9	S.-WSW.
Talthybius, Br. S. S.	Yokohama	Victoria	49 59 N.	148 00 W.	15	2 p., 16	16	29.46	SW	SSE., 10	SW	SSE., 11	Steady.
Iowa, Am. S. S.	Hong Kong	San Francisco	44 55 N.	180 00	15	—, 15	16	28.57	WSW	NW., 11	NW	NW., 11	SE.-NW.
Pres. Jackson, Am. S. S.	Yokohama	Victoria	50 24 N.	141 00 W.	15	3 p., 17	17	29.52	WSW	SSE., —	S	—, 11	Steady.
Sylvan Arrow, Am. S. S.	Hankow	San Pedro	45 18 N.	153 13 W.	16	11 p., 16	17	29.49	SW	SSW., 8	S	S., 11	SW.-S.
Hakutatsu Maru, Jap. S. S.	Muroran	Vancouver	49 34 N.	178 09 E.	17	Noon, 18	18	29.03	SE	W., 9	N	WSW., 10	W.-NW.
Reiyo Maru, Jap. S. S.	Miike	Longview, Oreg.	49 04 N.	144 30 W.	18	8 a., 18	18	29.21		SSW., —	SSW	SSW., 9	Steady.
Nevada, Am. S. S.	Portland	Yokohama	48 40 N.	170 20 E.	17	Midt., 17	19	29.00	WSW	WSW., 8	WNW	WNW., 11	WSW.-WNW.
Shiraha Maru, Jap. S. S.	Muroran	Grays Harbor	46 45 N.	163 52 E.	17	8 p., 17	20	29.50	WSW	W., 9	WNW	NW., 10	WSW.-W.
Tacoma, Am. S. S.	Philippines	San Francisco	43 37 N.	176 36 E.	20	7 a., 21	21	29.45	SSE	W., 2	NE	SE., 10	SW.-W.-NE.
Illinois, Am. S. S.	New York	Wilmington, Cal.	13 00 N.	93 26 W.	20	4 p., 20	21	29.86	NNW	NNW., 5	ENE	N., 9	Steady.
Pacific Spruce, Am. S. S.	San Pedro	Balboa	15 33 N.	95 39 W.	22	4 p., 23	24	29.86	NNE	N., 10	NW	NNE., 10	NNE.-N.
Lancaster, Am. S. S.	Balboa	San Francisco	13 45 N.	94 30 W.	23	8 p., 23	24	29.74	NNW	NNW., 6	NE	NNW., 9	NNW.-NNE.
La Perla, Am. S. S.	San Francisco	Balboa	15 03 N.	95 46 W.	23	4 a., 24	24	29.87	NE	NE., 9	NNW	NE., 9	NE.-N.-NNW.
Nevada, Am. S. S.	Portland	Yokohama	43 00 N.	143 30 E.	23	6 a., 23	24	29.24	W	W., 6	NW	NNW., 9	W.-NW.
Tacoma, Am. S. S.	Philippines	San Francisco	45 05 N.	166 50 W.	23	6 a., 24	24	29.18	SE	SSE., 4	S	SE., 10	SE.-SSE.-S.
Pres. Madison, Am. S. S.	Seattle	Yokohama	50 35 N.	178 30 W.	23		25	28.99	SE	SE., 7	NNE	NE., 9	ENE.-N.
Kurohime Maru, Jap. S. S.	Osaka	Seattle	50 00 N.	153 40 W.	23	8 p., 23	25	29.27		NW., 10		NW., 10	Steady.
Chief Capilano, Br. S. S.	do	Vancouver	49 35 N.	170 30 W.	23	6 p., 26	27	28.70	ESE	N., 9	NNW	E., 10	NNE.-N.
Satanta, Br. S. S.	Yokohama	San Pedro	40 47 N.	179 50 E.	28	9 p., 28	28	29.02	S	S., 8	SW	SE., 10	S.-SW.
Bessemer City, Am. S. S.	Honolulu	Kobe	32 10 N.	139 55 E.	28	4 p., 29	30	29.50	NE	NE., 10	NE	NE., 10	ENE.-NE.
Kentucky, Am. S. S.	Otaru	San Francisco	49 13 N.	166 36 E.	28	—, 30	30	28.94	NW	N., —	N	NW., 10	Steady.
Chief Capilano, Br. S. S.	Osaka	Vancouver	51 03 N.	155 51 W.	29	Noon, 30	30	29.24	ESE	SE., 9	SE	E., 10	E.-SE.
Pres. Jefferson, Am. S. S.	Yokohama	Honolulu	33 40 N.	155 00 W.	30	8 p., 30	Dec. 1	28.95	SE	NNW., 8	NNW	NNW., 10	S.-NNW.

NORTH PACIFIC OCEAN

By WILLIS E. HURD

Pressures were below the normal over the northern part of the ocean, with the Aleutian cyclone strongly developed, and central with an average of 29.30 inches over the western part of the Gulf of Alaska and the eastern Aleutians. Early in November this cyclone was of extraordinary depth, barometer readings even as far to the southeast as 43° N., 140° W., being as low as 28.20 inches on the 1st and 2d, and pressure at Dutch Harbor dropping to 27.92 on the 3d. Thereafter until the 20th pressures in the central part of the cyclone were frequently below 29 inches. At Midway Island, on the contrary, the barometer was above the normal for the month. Hence the gradients were abnormally steep between the thirtieth and fifty-fifth parallels.

The Pacific-California anticyclone was well developed during a goodly part of the month, but was subject to many deep incursions of the Aleutian cyclone on its northern and western sides. However, over much of its eastern and southern area it showed an average pressure slightly above the normal.

The following table gives an indication of the barometric conditions at several island and coast stations in west longitudes:

TABLE 1.—*Average, departures, and extremes of atmospheric pressure at sea level at indicated hours, North Pacific Ocean, November, 1928*

Stations	Average pressure	Departure from normal	Highest	Date	Lowest	Date
	Inches	*Inch*	*Inches*		*Inches*	
Dutch Harbor [1]	29.32	−0.27	30.06	23d	27.92	3d.
St. Paul [1] [2]	29.41	−0.21	30.06	23d [5]	28.28	3d.
Kodiak [1]	29.30	−0.24	30.12	30th	28.12	2d.
Midway Island [1]	30.14	+0.07	30.38	19th	29.74	28th.
Honolulu [3]	30.05	+0.03	30.23	12th	29.89	1st.
Juneau [3]	29.74	−0.02	30.36	17th	28.86	3d.
Tatoosh Island [3] [4]	30.03	+0.06	30.70	17th	29.37	13th.
San Francisco [3] [4]	30.13	+0.03	30.42	17th	29.65	13th.
San Diego [3] [4]	30.05	+0.05	30.28	16th	29.82	5th.

[1] P. m. observations only.
[2] For 29 days.
[3] A. m. and p. m. observations.
[4] Corrected to 24-hour mean.
[5] Also on 24th.

November set in with high winds occurring along almost the entire width of the ocean above the fortieth parallel, and full storm to hurricane velocities blowing here and there over a considerable stretch of the upper steamship routes from the 1st to the 4th. While most of the more violent gales were due to the great temporary intensity of the permanent winter cyclone, those on the extreme west resulted from the presence of an Asiatic cyclone that, quitting the continent on the 2d, entered the sea as a powerful storm, via extreme northern Japan, on the 3d. In addition, anticyclonic gales of moderate to strong force blew in the neighborhood of the thirtieth parallel, west of the one hundred and eightieth meridian, during the same period. On the 11th a southerly gale of force 11 was encountered off the Oregon coast, in connection with a cyclone that later moved into British Columbia. From the 15th to the 17th, during another period of great intensification of the Aleutian cyclone, and while another violent extratropical storm was emerging upon the sea from northern Japan, gales of forces 11 to 12 again swept over an enormous area of the upper traveled routes between 140° W. and 170° E.

Aside from these winds of higher velocities, on several dates, lesser gales were of daily occurrence here and there over the upper waters of the Pacific. In some individual 5-degree squares between 45° and 50° N., both east and west of the one hundred and eightieth meridian, winds of force 8 or over occurred on at least 10 days of the month.

A report on the two typhoons of the month, by the Rev. José Coronas, of the Philippine Weather Bureau, is subjoined. It may be added that one of our observing steamers, the *Bessemer City*, Honolulu to Kobe, after experiencing continuous rain for 44 hours, ran across the front of the second typhoon in a northeast gale of force 10, near 32° N., 140° E., on the 29th.

One of the most interesting meteorological incidents of the month was the occurrence of a moderate to very strong norther over and far to the southward of the Gulf of Tehuantepec, from the 20th to 26th, coincident with the presence of a well-developed anticyclone over the United States. The strongest gale noted was from NNE., force 10, in 15° 33′ N., 95° 39′ W., on the 23d, although a 70-mile gale—a so-called "hurricane"—was reported by the press as having been encountered on the morning of the 24th by the U. S. S. *Maryland*, en route southward with President-elect Hoover on board. The master of the British tanker *Ontariolite*, Talara, Peru, to Vancouver, reported a high northeast sea and gale in low latitudes from after midnight of the 23d until 4 p. m. of the 24th. At noon of the 24th this vessel was in 11° 25′ N., 97° 59′ W.

At Honolulu the prevailing wind was from the east, and the maximum velocity was 36 miles from the east on the 4th.

Fog was infrequent over the ocean as a whole, and occurred on only a few scattered dates along the northern steamer passages. The most important fog area lay from the California coast to the one-hundred and thirty-fifth meridian, between latitudes 35° and 40° N., where it was reported on 10 days. It was observed on at least four days in coastal waters between 30° and 35° N., and in the Gulf of Tehuantepec on one day.

Waterspouts.—The following report of waterspouts was furnished by Mr. G. G. Foster, observer of the American steamer *Columbian*, J. McAvoy, master, Balboa to Los Angeles:

November 4, 1928. Waterspouts. Lat. 15° 24′, N., long. 98° 32′ W., from 15.53 to 16.02. Experienced a series of four water spouts, one at a time, first one largest, all starting from sea first, later from clouds, and joining each other two-thirds of distance to clouds. First spout vertical; succeeding ones progressing in inclination with tops to SE. of bottoms. Wind WNW. 5, small sea, temperature of air 80°, of water 83°, barometer 29.83, clouds Cu.Nb.
November 4. Lat. 15° 26′ N., long. 98° 40′ W., 16.01 to 16.14. Experienced two waterspouts on port hand. Both starting in clouds and reaching three-fourths way to water. Tails streaming to SE., with lightning around both. Starting at different times, but both ending together.

Lunar rainbows.—Mr. L. G. Vick, observer of the American steamer *Mauna Ala*, H. S. Sawyer, master, Kahului to Bellingham, reports as follows:

During the hours of 12 to 4 a. m., November 25–26, numerous lunar rainbows at intervals observed. Weather overcast, cloudy; light passing rain squalls. Moon full. (Position at 3.30 a. m., 26th, 47° 21′ N., 127° 26′ W.)

SOUTH PACIFIC OCEAN

Smoke.—Mr. William H. Stewart, observer on board the American steamer *Ventura*, William R. Meyer, master, Pago Pago to Sydney, reports:

While standing in toward the N. S. W. coast, in the vicinity of Sydney, November 8, 1928, at 2 a. m., we encountered smoke due to the bush fires in Queensland, the wind being NW. At 5 a. m. the smoke became so thick the visibility was about 2 miles—impossible to take sights.

TYPHOONS AND DEPRESSIONS

A MOST DESTRUCTIVE TYPHOON OVER THE CENTRAL PART OF THE PHILIPPINES NOVEMBER 23 AND 24, 1928

By Rev. José Coronas, S. J.

[Weather Bureau, Manila, P. I.]

On November 23 the Philippines were visited by one of the most destructive typhoons we have experienced in recent years, causing along its path very great damages to the crops and property, and a considerable loss of lives, probably from 100 to 200, in spite of the timely warnings wired to the threatened Provinces by the Weather Bureau. The interisland steamer *Euzcadi* was completely wrecked near the northern coast of Samar, and the Japanese steamer *Saka Maru* was grounded on the shores of Masbate. Several other ships and boats were either wrecked or grounded in the interisland seas south of Luzon.

The origin of this typhoon was in the neighborhood of 145° longitude E., between 8° and 9° latitude N., over the Western Carolines to the south of Guam, on the 18th to 19th of November.

It moved WNW. on the 19th, W. by N. on the 20th, and practically due W. on the 21st, with a little inclination to WSW on the 22d, the rate of progress of the storm during those days being about 12 or 13 miles per hour. While traversing the Philippines the rate of progress between Samar and Mindoro was only about 10 miles per hour and the direction of the typhoon was WNW.

The center of the typhoon entered the Philippines at 3 a. m. of the 23d across the eastern coast of Samar to the north of Borongan, where a barometric minimum as low as 710.71 mm. (27.98 ins.)[1] was recorded. After Samar the center traversed Masbate Island, passed near to the north of Romblon, and reached Mindoro Island shortly after midnight of the 23d. From Mindoro the track of the typhoon inclined to NW. by W. This direction was kept practically until the evening of the 25th.

For nearly two days the typhoon remained almost stationary over the China Sea in the neighborhood of 116° longitude E. and 17° latitude N., while it completed a very acute recurve to the E., thus threatening the northern part of Luzon. Yet the typhoon had lost already much of its former intensity, and so it was forecast by the Weather Bureau that not much stormy weather was to be expected in northern Luzon at the passing of the center in its movement to the east. It was about 7.30 p. m. when the typhoon struck the western coast of northern Luzon close to Vigan, where a barometric minimum not lower than 745.18 mm. (29.34 ins.)[1] was observed, and the winds blew with a force not greater than 7 (Beaufort scale). After striking the coast, the storm became less and less deep so as to appear on our weather maps as a shallow depression of little importance.

The approximate positions of the center at 6 a. m. during the period of November 20 to 29 were as follows:

November 20, 6 a. m.	139° 45′ longitude E.,	10° 40′ latitude N.
November 21, 6 a. m.	134° 30′ longitude E.,	12° 00′ latitude N.
November 22, 6 a. m.	129° 35′ longitude E.,	12° 15′ latitude N.
November 23, 6 a. m.	125° 00′ longitude E.,	11° 50′ latitude N.
November 24, 6 a. m.	121° 10′ longitude E.,	13° 00′ latitude N.
November 25, 6 a. m.	117° 45′ longitude E.,	15° 00′ latitude N.
November 26, 6 a. m.	116° 00′ longitude E.,	17° 00′ latitude N.
November 27, 6 a. m.	116° 00′ longitude E.,	17° 00′ latitude N.
November 28, 6 a. m.	117° 55′ longitude E.,	17° 45′ latitude N.
November 29, 6 a. m.	123° 00′ longitude E.,	17° 10′ latitude N.

The Provinces that suffered most the effects of this destructive typhoon either by hurricane winds or by heavy floods or storm waves were Samar, northern Leyte, Sorsogon, Albay, Masbate, Capiz, Romblon, Marinduque, the southernmost part of Tayabas and Mindoro.

Besides the Philippine typhoon there was another, also very severe, over the Pacific, which fortunately did not strike either the Philippines or Japan, but remained over the Pacific after recurving to the southeast of the Loochoos.

The first signs of the formation of this typhoon were shown by our weather maps of November 21, 6 a. m., to the WSW. of Ponape in about 154° longitude E. and 5° latitude N. It moved NW. by W. until the morning of the 25th, NW. from the afternoon of the 25th to the evening of the 27th, when it began to incline to the N. On the 28th it completed the recurve northeastward, and in the afternoon of the 29th it passed not far to the north of the Bonins, moving ENE. Its center could still be noticed at 6 a. m. of the 30th in about 150° longitude E. and 30° latitude N., moving eastward. The barometric reading recorded at Chichijima (Bonin Islands) at noon of the 29th was 745.5 mm. (29.35 ins., gravity correction applied) when the center was about 150 miles to the WNW. of that station.

The approximate positions of the center at 6 a. m. of the period November 24 to 30 were as follows:

November 24, 6 a. m.	145° 45′ longitude E.,	9° 45′ latitude N.
November 25, 6 a. m.	143° 05′ longitude E.,	11° 10′ latitude N.
November 26, 6 a. m.	139° 15′ longitude E.,	13° 45′ latitude N.
November 27, 6 a. m.	135° 30′ longitude E.,	17° 20′ latitude N.
November 28, 6 a. m.	132° 40′ longitude E.,	20° 20′ latitude N.
November 29, 6 a. m.	137° 00′ longitude E.,	26° 15′ latitude N.
November 30, 6 a. m.	150° 00′ longitude E.,	30° 00′ latitude N.

The U. S. S. *Ramapo* was not far from the center of this typhoon at 12 m. n. of the 27th when she reported a barometric reading 29.48 ins. (corrected for gravity) and winds from SW. by W., force 7, in 131° 00′ longitude E., 18° 20′ latitude N.

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[1] Gravity correction not applied.

CLIMATOLOGICAL TABLES[1]

CONDENSED CLIMATOLOGICAL SUMMARY

In the following table are given for the various sections of the climatological service of the Weather Bureau the monthly average temperature and total rainfall; the stations reporting the highest and lowest temperatures, with dates of occurrence; the stations reporting the greatest and least total precipitation; and other data as indicated by the several headings.

The mean temperature for each section, the highest and lowest temperatures, the average precipitation, and the greatest and least monthly amounts are found by using all trustworthy records available.

The mean departures from normal temperatures and precipitation are based only on records from stations that have 10 or more years of observations. Of course, the number of such records is smaller than the total number of stations.

Condensed climatological summary of temperature and precipitation by sections, November, 1928

Section	Temperature		Monthly extremes						Precipitation		Greatest monthly		Least monthly	
	Section average	Departure from the normal	Station	Highest	Date	Station	Lowest	Date	Section average	Departure from the normal	Station	Amount	Station	Amount
	°F.	°F.		°F.			°F.		In.	In.		In.		In.
Alabama	53.3	−0.8	Talladega	85	17	Riverton	16	26	2.15	−0.93	St. Bernard	5.11	2 stations	0.30
Arizona	51.1	−1.4	Parker	90	11	Alpine	−3	28	0.54	−0.32	Bly Ranger Station	2.48	8 stations	0.00
Arkansas	50.2	−1.4	3 stations	82	[2]8	Dutton	13	26	4.25	+0.60	Bee Branch	7.71	Blytheville	1.80
California	51.4	−1.0	Indio	93	20	Sierraville	4	17	3.02	+0.56	Crescent City	9.63	2 stations	0.00
Colorado	34.1	−1.2	Lamar	77	13	Hermit	−24	30	1.73	+0.90	La Veta Pass	5.85	Haxtun	.33
Florida	64.2	−0.8	Venus	93	7	Jacksonville No. 2	23	27	0.69	−1.52	Panama City	2.41	4 stations	T.
Georgia	54.2	−0.3	St. George	87	19	Clayton	11	26	0.94	−1.71	Blue Ridge	3.11	2 stations	0.1
Idaho	36.0	+0.1	2 stations	70	[2]10	2 stations	−15	18	1.31	−0.87	Roland	3.23	Salmon	0.09
Illinois	43.3	+1.2	Harrisburg	75	16	do	15	[2]25	3.77	+1.37	Freeport	6.08	Morrisonville	1.49
Indiana	43.5	+1.3	Madison	77	17	Marengo	11	26	3.16	+0.07	Salem	4.84	Covington	1.53
Iowa	38.7	+2.1	3 stations	70	15	2 stations	8	[2]3	3.83	+2.28	Mount Ayr	6.83	Lake Park	0.77
Kansas	43.3	−0.9	4 stations	77	[2]11	Gove (near)	10	20	4.41	+3.07	Lebo	13.03	Gove (near)	0.58
Kentucky	46.8	+0.5	3 stations	78	17	2 stations	10	26	3.93	+0.40	Middlesboro	7.51	Lockport	2.55
Louisiana	58.0	−0.9	Schriever	89	18	do	22	26	3.20	−0.38	Delta Farms	9.14	Schriever	1.55
Maryland-Delaware	47.1	+2.5	Ferry Landing, Md.	80	18	do	13	26	1.88	−0.66	Oakland, Md	4.23	2 stations	1.04
Michigan	38.0	+1.6	Bay City	74	[2]15	Humboldt	−2	29	3.24	+0.86	Ganges	6.37	Alpha	0.45
Minnesota	33.6	+3.8	Montevideo	64	13	Grand Marais	0	25	0.51	−0.57	Red Lake Falls	1.66	Redby	T.
Mississippi	54.3	−0.8	Port Gibson	85	16	Tupelo	17	26	3.24	−0.28	Rosedale	5.98	Natchez	1.55
Missouri	44.6	+0.1	Marshall	79	15	Neosho	9	26	5.10	+2.75	Centerview	10.88	St. Charles	0.74
Montana	33.6	+1.8	Valentine	72	22	2 stations	−14	[2]18	0.34	−0.58	Heron	2.96	19 stations	0.00
Nebraska	37.5	+0.8	Sidney	78	14	Purdum	0	3	1.90	+1.16	Auburn	6.28	Fort Robinson	0.19
Nevada	40.0	−0.5	Logandale	80	[2]6	Millett	−4	30	0.53	−0.13	Tuscarora	1.88	2 stations	0.00
New England	38.1	+0.2	Nashua, N. H	79	16	Van Buren, Me	−8	30	2.18	−1.32	New London, Conn	5.05	Bethlehem, N. H	0.70
New Jersey	45.1	+2.4	Indian Mills	78	18	2 stations	13	26	1.90	−1.24	Indian Mills	2.76	2 stations	1.20
New Mexico	40.2	−2.3	Elk	80	11	Selsor Ranch	−20	30	1.08	+0.49	Raton	4.73	Tatum	T.
New York	39.9	+2.3	3 stations	76	[2]15	Indian Lake	−3	28	2.91	+0.04	High Market	4.94	Cairo	0.69
North Carolina	50.4	+0.6	Kinston	85	19	Mount Mitchell	−1	26	1.57	−0.85	Beaufort	6.35	Rockingham	0.25
North Dakota	31.0	+4.4	Carson	70	5	Berthold Agency	−11	21	0.48	−0.10	Linton	2.48	5 stations	0.00
Ohio	43.3	+1.8	Portsmouth	80	17	Bangorville	11	26	3.00	+0.36	Middletown	4.75	North Bass Island	1.55
Oklahoma	48.5	−1.7	Tishomingo	79	14	Boise City	1	19	3.42	+1.42	Newkirk	8.56	Hooker	1.37
Oregon	41.7	0.0	Cottage Grove	72	2	Lake	2	[2]18	3.54	−1.33	Valsetz	16.95	Lake	0.36
Pennsylvania	43.4	+2.4	Lancaster	81	[2]18	Montrose	4	26	2.32	−0.49	Westford	5.71	Sunbury	1.05
South Carolina	52.8	−0.8	4 stations	81	[2]18	Caesars Head	11	26	0.72	−1.53	Caesars Head	3.11	Blackville	0.09
South Dakota	34.9	+1.2	Centerville	79	14	Vale	−4	3	0.96	+0.32	2 stations	2.29	Lemmon	0.00
Tennessee	48.8	+0.4	Etowa	82	15	Rugby	10	26	3.56	−0.01	Rugby	7.02	Embreeville	1.18
Texas	55.5	−1.6	Harlingen	92	1	Romero	0	19	2.62	+0.28	Cuero	8.34	Sterling City	0.00
Utah	37.8	+0.3	2 stations	75	[2]11	Woodruff	−10	18	1.44	+0.42	Silver Lake	4.90	Fort Duchesne	0.02
Virginia	48.1	+1.7	Hopewell	83	[2]17	Burkes Garden	11	26	1.34	−1.01	Dante	3.15	Winchester	0.60
Washington	39.7	0.0	2 stations	69	[2]20	3 stations	7	2	3.39	−2.05	Wynoochee Oxbow	17.30	Irene Mountain	0.27
West Virginia	44.0	+1.4	Moorefield	81	[2]3	Pickens	9	[2]26	3.31	+0.52	Pickens	9.41	Upper Tract	0.65
Wisconsin	36.1	+2.6	2 stations	68	[2]15	Long Lake	2	23	1.92	+0.10	Williams Bay	5.91	Superior	0.17
Wyoming	30.5	−0.7	do	70	[2]10	Riverside	−26	18	1.08	+0.38	Middle Fork (near)	2.92	Deaver	0.24
Alaska (October)	29.0	−1.7	Sitka	61	31	Fort Yukon	−13	20	3.12	−0.56	Cordova	26.14	Fort Yukon	0.07
Hawaii	71.8	+0.3	Kaanapali	96	[2]7	Kula Sanitarium	49	[2]28	9.96	+1.55	Intake, Wainiha Power Canal.	47.65	Ka Lae	0.00
Porto Rico	78.0	+1.3	San German	96	13	San German	57	28	7.83	+0.62	Toro Negro	15.87	San Francisco	3.05

[1] For description of tables and charts, see Review, January, 1929, p. 29.

[2] Other dates also.

TABLE 1.—*Climatological data for Weather Bureau stations, November, 1928*

District and station	Elevation of instruments			Pressure			Temperature of the air												Precipitation			Wind										
	Barometer above sea level	Thermometer above ground	Anemometer above ground	Station reduced to mean of 24 hours	Sea level, reduced to mean of 24 hours	Departure from normal	Mean max. + mean min. ÷ 2	Departure from normal	Maximum	Date	Mean maximum	Minimum	Date	Mean minimum	Greatest daily range	Mean wet thermometer	Mean temperature of the dew-point	Mean relative humidity	Total	Departure from normal	Days with .01, or more	Total movement	Prevailing direction	Maximum velocity: Miles per hour	Maximum velocity: Direction	Maximum velocity: Date	Clear days	Partly cloudy days	Cloudy days	Average cloudiness, tenths	Total snowfall	Snow, sleet, and ice on ground at end of month
	Ft.	Ft.	Ft.	In.	In.	In.	°F.	°F.	°F.		°F.	°F.		°F.	°F.	°F.	°F.	%	In.	In.		Miles								0–10	In.	In.
New England							41.3	+1.8										73	2.37	−0.8										6.6		
Eastport	76	67	85	29.82	29.90	−0.11	36.6	−0.1	59	19	43	14	27	30	32	33	28	71	1.71	−1.6	12	6,852	w.	38	s.	19	6	5	19	7.3	2.5	T.
Greenville, Me	1,070	6		28.74	29.93		30.7		59	15	38	8	30	24	27				2.71		12		nw.				9	8	13		6.5	
Portland, Me	103	82	117	29.85	29.97	−.04	39.6	+1.6	68	15	47	15	28	32	28	34	28	68	1.62	−1.8	10	5,680	n.	34	nw.	6	8	8	14	6.4	0.8	T.
Concord	289	70	79	29.65	29.97	−.09	38.5	+0.8	71	17	48	8	28	29	31				1.95	−1.1	9	3,422	nw.	25	w.	6	9	7	14	5.9	11.5	5.3
Burlington	403	11	48	29.53	29.98	−.07	36.4	+0.1	65	15	43	13	27	29	28				2.27	−0.4	15	6,606	s.	35	nw.	6	3	7	20	7.8	4.2	1.6
Northfield	876	12	60		29.98	−.07	34.2	+1.4	64	17	43	3	28	25	36			81	2.24	−0.4	15	3,647	n.	30	sw.	6	2	8	20	7.8	6.5	3.0
Boston	125	115	188	29.83	29.97	−.08	44.8	+2.8	76	17	52	18	26	37	26	30	34	60	1.85	−1.5	10	6,178	sw.	32	w.	6	5	7	18	7.1	1.4	0.0
Nantucket	12	14	90	29.96	29.97	−.08	45.4	+1.0	63	4	51	22	26	40	23	42	38	76	4.24	+1.0	11	10,114	w.	37	sw.	6	3	11	16	7.3	0.6	0.0
Block Island	26	11	46	29.94	29.97	−.09	46.0	+1.4	62	19	51	24	26	41	18	42	37	73	2.58	−1.0	10	12,678	w.	44	w.	27	6	13	11	5.9	0.2	0.0
Providence	160	215	251	29.81	29.98	−.09	44.2	+3.8	72	17	52	20	26	36	27	39	32	67	2.13	−0.9	8	7,271	nw.	42	nw.	6	10	11	9	5.5	T.	T.
Hartford	159	122		29.81	29.99	−.09	43.6	+4.1	72	17	51	19	26	36	28				1.88	−1.7	8		sw.				9	10	11	5.6	T.	T.
New Haven	106	74	153	29.89	30.01	−.06	44.5	+2.5	71	16	51	21	26	38	23	41	37	78	3.50	+0.2	9	5,617	sw.	26	sw.	19	8	10	12	6.0	T.	0.0
Middle Atlantic States							47.3	+2.6										72	1.74	−0.8										6.6		
Albany	97	108	115	29.89	30.00	−.08	42.6	+3.3	73	17	50	19	26	36	25	37	33	74	1.59	−1.2	12	4,107	nw.	22	w.	6	9	8	13	6.0	1.6	0.9
Binghamton	871	10	84	29.06	30.01	−.08	41.6	+2.9	70	18	49	17	26	35	28				2.11	−0.2	15	3,879	nw.	30	w.	19	6	4	20	7.3	5.1	0.0
New York	314	414	454	29.69	30.03	−.06	46.6	+2.4	71	18	53	21	26	40	19	41	35	68	2.16	−0.8	10	11,190	nw.	48	sw.	19	3	14	13	7.3	T.	0.0
Bellefonte	1,050	5	36	28.91	30.04		41.2		72	17	50	17	26	32	34	37	34	79	1.23		10		w.				2	5	23	8.1	1.7	0.0
Harrisburg	374	94	104	29.66	30.07	−.04	46.4	+3.6	76	18	54	23	26	39	29	41	35	67	2.25	−0.1	7	4,286	w.	40	sw.	19	4	10	16	7.0	T.	0.0
Philadelphia	114	123	367	29.93	30.06	−.04	49.0	+3.3	74	18	56	25	26	42	23	44	39	73	1.94	−0.8	8	9,007	sw.	41	sw.	19	4	10	16	7.0	T.	0.0
Reading	325	81	98	29.69	30.05		47.2		77	18	54	23	26	40	28	41	36	71	2.03	−1.1	8	4,105	w.	22	w.	6	1	13	16	7.5	0.1	0.0
Scranton	805	111	119	29.15	30.03	−.06	43.0	+2.5	72	18	50	18	26	36	26	39	35	76	1.88	−0.4	12	4,404	sw.	39	sw.	19	5	3	22	8.1	0.6	0.0
Atlantic City	52	37	172	29.99	30.05	−.05	48.2	+2.6	68	16	55	22	26	42	28	44	39	75	1.87	−1.0	10	11,134	w.	44	nw.	8	7	10	13	6.3	0.0	0.0
Cape May	17	13	49				48.8	+1.4	72	18	56	26	26	42	26	44	41	77	1.30		7		nw.				5	14	11		T.	0.0
Sandy Hook	22	10	55	30.00	30.02		46.7		67	18	52	25	26	42	16	42	38	74	1.89		10	10,329	sw.	41	nw.	8	3	13	14	6.8	T.	0.0
Trenton	190	159	183	29.83	30.04		46.6		73	18	54	21	26	39	26	41	37	74	1.91	−1.5	9	6,651	sw.	35	sw.	19	3	14	13	7.1	T.	0.0
Baltimore	123	100	215	29.94	30.07	−.04	50.3	+4.0	78	18	58	26	26	42	25	44	38	69	1.78	−0.8	7	6,628	sw.	38	nw.	8	6	13	11	6.4	T.	0.0
Washington	112	62	85	29.96	30.08	−.04	49.4	+4.2	78	18	58	23	26	40	30	42	37	69	2.01	−0.4	8	4,191	nw.	25	nw.	8	5	13	12	6.3	0.2	0.0
Cape Henry	18	8	54	30.07	30.09		53.0		80	19	60	28	27	46	27	47	42	71	1.47	−0.9	10	9,656	sw.	47	nw.	25	11	9	10	5.3	0.0	0.0
Lynchburg	681	153	188	29.36	30.12	−.01	49.8	+2.6	77	15	60	22	26	39	34	43	38	69	0.79	−1.5	6	5,429	nw.	30	sw.	19	10	14	6	4.8	0.0	0.0
Norfolk	91	170	205	30.02	30.12	+.01	52.3	+0.9	77	19	60	27	26	44	26	46	40	70	1.92	−0.2	10	9,222	sw.	38	nw.	26	11	7	12	5.3	T.	0.0
Richmond	144	11	52	29.96	30.12	.00	50.4	+2.1	80	18	60	24	26	40	31	43	38	70	1.20	−1.0	9	5,941	sw.	30	nw.	22	12	8	10	5.1	T.	0.0
Wytheville	2,304	49	55	27.72	30.15	+.02	43.6	+0.6	69	18	53	17	25	34	37	38	33	72	0.92	−1.2	10	5,032	w.	29	sw.	19	7	9	14	6.4	0.9	0.0
South Atlantic States							54.5	+0.4										72	1.26	−1.1										4.4		
Asheville	2,253	70	84	27.77	30.17	+.03	46.8	+1.7	71	3	57	18	26	37	33	40	35	72	0.89	−1.4	6	6,618	nw.	27	n.	25	12	6	12	5.1	T.	0.0
Charlotte	779	55	62	29.31	30.16	+.03	51.4	+0.8	76	18	61	22	26	42	32	45	40	72	0.52	−2.0	5	3,402	sw.	19	nw.	25	14	4	12	4.7	0.0	0.0
Greensboro	886	5	56	29.20	30.17		47.4		77	18	60	16	26	35	37	41	37	78	0.76		6	5,603	sw.	30	sw.	19	16	6	8	4.2	0.0	0.0
Hatteras	11	11	50	30.10	30.11	.00	56.1	−0.2	78	2	62	30	26	50	24	52	49	79	4.79	+1.3	11	9,879	nw.	60	n.	11	12	12	6	4.6	0.0	0.0
Raleigh	376	103	110	29.74	30.15	+.02	52.2	+1.2	76	18	62	23	26	42	30	45	39	69	0.54	−1.8	7	5,213	sw.	23	nw.	25	13	9	8	4.4	0.0	0.0
Wilmington	78	81	91	30.08	30.16	+.04	55.4	−0.6	80	18	64	27	26	46	29	50	46	79	2.74	+0.8	7	4,137	w.	23	sw.	19	15	9	6	4.1	0.0	0.0
Charleston	48	11	92	30.12	30.17	+.05	57.6	−0.5	80	18	65	32	26	50	27	51	46	72	1.03	−1.1	4	6,406	n.	27	ne.	9	16	5	9	4.1	0.0	0.0
Columbia, S. C	351	41	57	29.79	30.18	+.06	54.0	0.0	80	18	64	24	26	44	29	46	41	69	0.21	−2.0	3	4,275	n.	27	s.	19	14	6	10	4.3	0.0	0.0
Due West	711	10	55	29.42	30.20		51.4		77	17	62	18	26	40	38				0.76		4	5,519	sw.	24	w.	22	15	4	11	4.3	0.0	0.0
Greenville, S. C	1,039	139	146	29.05	30.16		52.2	+2.6	74	17	62	22	26	43	33	44	38	65	0.88		4	5,239	sw.	30	s.	19	13	7	10	4.5	0.0	0.0
Augusta	182	62	77	29.97	30.17	+.04	55.0	+0.5	82	18	66	28	26	44	34	47	42	71	0.30	−2.1	3	3,215	nw.	22	sw.	30	15	7	8	4.0	0.0	0.0
Savannah	65	150	194	30.11	30.18	+.06	58.2	−0.3	80	19	67	31	26	49	28	50	45	72	0.90	−1.2	6	7,124	nw.	30	w.	22	15	6	9	4.2	0.0	0.0
Jacksonville	43	209	245	30.12	30.17	+.07	61.0	−1.2	80	17	69	34	26	53	26	54	49	72	0.67	−1.3	4	7,140	n.	27	sw.	19	9	13	8	5.1	0.0	0.0
Florida Peninsula							70.3	−0.7										76	0.94	−1.3										5.1		
Key West	22	10	64	30.05	30.07	+.05	73.4	−0.9	86	6	78	58	21	69	14	67	65	80	2.34	+0.2	7	6,984	ne.	24	nw.	10	14	10	6	4.3	0.0	0.0
Miami	25	71	164	30.07	30.10		71.8	−0.2	87	8	77	47	22	66	21	65	62	73	0.42	−2.4	9	7,836	e.	29	e.	15	4	11	15	6.7	0.0	0.0
Tampa	35	79	87	30.10	30.14	+.06	65.8	−1.1	84	17	75	40	26	56	28	58	54	74	0.05	−1.7	2	4,506	ne.	18	ne.	14	8	14	8	5.2	0.0	0.0
Titusville	44	5		30.09	30.14		66.6		88	19	76	32	22	57	38				0.30		3		w.				15	7	8	4.3	0.0	0.0
East Gulf States							55.4	−0.7										72	2.12	−1.2										4.6		
Atlanta	1,173	190	216	28.93	30.19	+.06	51.4	−0.7	76	17	60	23	26	43	27	45	38	67	1.21	−1.8	5	7,843	nw.	35	nw.	22	11	9	10	4.5	0.0	0.0
Macon	370	78	87	29.79	30.20	+.07	53.8	−0.4	81	18	64	26	26	43	36	46	41	71	0.73	−2.4	5	3,947	nw.	19	nw.	22	15	5	10	4.1	0.0	0.0
Thomasville	273	49	58	29.88	30.19	+.07	57.2	−1.3	81	18	67	29	26	47	29	49	45	75	1.10	−1.5	5	2,628	nw.	16	sw.	30	10	10	10	5.2	0.0	0.0
Apalachicola	36	42	49	30.14	30.18		58.6		76	18	66	33	26	51	24	53	50	79	0.55		2	5,519	n.	23	ne.	26	18	8	4	3.4	0.0	0.0
Pensacola	56	149	185	30.13	30.19	+.08	58.1	−2.1	75	18	65	31	26	51	24	52	48	73	1.44	−2.3	6	9,221	n.	44	s.	19	8	13	9	5.3	0.0	0.0
Anniston	741	9	57	29.42	30.23	+.11	51.4	−0.5	81	17	62	20	26	40	35				2.79	−0.6	5	3,388	nw.	17	nw.	20	15	7	8	4.0	0.0	0.0
Birmingham	700	11	48	29.43	30.21	+.09	53.3	−0.6	77	17	63	24	26	44	34	45	39	68	2.20	−1.2	5	4,574	nw.	22	se.	17	14	3	13	4.8	0.0	0.0
Mobile	57	125	161	30.13	30.19	+.08	58.0	−0.6	77	17	67	32	26	49	30	51	47	73	1.61	−2.0	5	6,875	n.	28	sw.	19	8	16	6	5.3	0.0	0.0
Montgomery	223	100	112	29.95	30.21	+.09	55.6	−0.2	80	17	66	28	26	46	30	47	40	64	1.07	−2.2	5	4,329	n.	23	nw.	19	14	7	9	4.4	0.0	0.0
Corinth	469	6					51.6		78	15	61	21	26	42	36				2.64		8						7	14	9		0.0	0.0
Meridian	375	87	95	29.79	30.20	+.08	54.3	+0.1	80	16	65	27	26	44	34	47	43	75	3.00	−1.1	9	3,690	n.	17	nw.	20	14	5	11	4.8	0.0	0.0
Vicksburg	247	65	73	29.93	30.21	+.09	55.4	−1.2	81	16	64	30	26	46	29	49	44	72	3.08	−0.6	9	4,363	se.	21	nw.	17	12	7	11	5.0	0.0	0.0
New Orleans	53	76	84	30.13	30.19	+.09	61.4	−0.2	83	17	69	37	26	54	23	54	49	72	5.10	+2.0	7	4,388	ne.	20	nw.	19	15	6	9	4.4	0.0	0.0
West Gulf States							56.9	−0.9										76	3.07	+0.1										5.7		
Shreveport	249	77	93	29.92	30.20	+.09	55.2	−0.8	78	16	64	33	26	46	30	49	43	72	2.87	−0.8	13	3,743	se.	18	w.	17	16	3	11	4.8	0.0	0.0
Bentonville	1,303	11	44	28.75	30.14	+.03	46.4	−0.3	72	14	55	21	26	37	32				4.74		9		s.		s.		16	1	13		T.	0.0
Fort Smith	457	79	94	29.67	30.16	+.05	49.5	−1.5	73	14	58	29	26	41	34	44	40	75	2.45	−0.4	8	5,067	e.	30	sw.	16	7	9	14	6.3	T.	0.0
Little Rock	357	136	153	29.79	30.18	+.06	51.4	−0.7	74	16	59	30	26	43	36	45	40	71	2.50	−2.0	7	5,537	s.	24	sw.	17	10	7	13	5.7	0.0	0.0
Austin	605	136	148	29.52	30.16		57.6	−0.9	84	7	67	34	20	48	35	52	48	76	2.18	−0.1	11	4,729	n.	29	se.	16	10	5	15	6.0	0.0	0.0
Brownsville	57	53	61	30.05	30.10		67.2	0.0	85	1	74	48	20	60	23	61	58	81	4.88	+2.9	7	4,573	n.	24	n.	9	7	14	9	6.1	0.0	0.0
Corpus Christi	20	11	78	30.12	30.14	+.07	64.6	+0.3	86	1	70	44	21	59	21	60	57	82	3.09	+0.7	7	6,705	n.	31	se.	16	4	11	15	6.9	0.0	0.0
Dallas	512	220	227	29.62	30.18		53.9		79	16	62	33	3	46	26				1.61		7	7,756	se.	37	sw.	16	12	6	12	5.4	T.	0.0
Fort Worth	670	106	114	29.44	30.16	+.06	54.8	−0.7	81	14	64	33	20	46	28	49	45	70	1.97	−0.6	8	5,233	se.	32	s.	16	9	7	14	6.1	0.0	0.0
Galveston	54	106	114	30.12	30.18	+.06	62.4	−0.9	80	1	68	44	3	57	21	58	55	82	3.87	+0.5	10	6,868	n.	27	n.	2	11	10	9	4.8	0.0	0.0
Groesbeck	461	11	56	29.67	30.16		55.4		81	16	65	34	4	46	34				1.41		12	6,080	n.	37	s.	16	9	8	13	5.7	0.0	0.0
Houston	138	292	314	30.03	30.18		60.2	−1.1	81	15	68	39	3	52	24				2.66	−1.0	14	8,134	e.	37	se.	16	11	9	10	5.3	0.0	0.0
Palestine	510	64	72	29.64	30.19	+.08	54.9	−2.3	80	15	64	31	3	46	31	50	45	74	6.59	+3.2	10	4,458	nw.	25	se.	16	10	5	15	5.6	0.0	0.0
Port Arthur	34	58	66	30.13	30.17		60.2		78	1	68	40	3	53	28	55	52	83	4.44		11	4,751	n.	24	nw.	17	13	6	11	5.0	0.0	0.0
San Antonio	693	119	132	29.42	30.16	+.08	59.4	−0.9	82	7	68	38	20	50	29	52	47	70	2.29	+0.4	6	4,162	ne.	25	nw.	16	12	3	15	5.9	0.0	0.0
Taylor	583	55	63	29.58	30.20	+.12	56.6	−1.1	81	7	66	33	20	47	38				1.43	−1.2	9	4,753	nw.	26	s.	16	10	7	13	5.4	0.0	0.0

TABLE 1.—*Climatological data for Weather Bureau stations, November, 1928*—Continued

District and station	Elevation of instruments: Barometer above sea level	Elevation: Thermometer above ground	Elevation: Anemometer above ground	Pressure: Station reduced to mean of 24 hours	Pressure: Sea level, reduced to mean of 24 hours	Pressure: Departure from normal	Temperature: Mean max. + mean min. ÷ 2	Temperature: Departure from normal	Temperature: Maximum	Temperature: Date	Temperature: Mean maximum	Temperature: Minimum	Temperature: Date	Temperature: Mean minimum	Temperature: Greatest daily range	Mean wet thermometer	Mean temperature of dew-point	Mean relative humidity	Precipitation: Total	Precipitation: Departure from normal	Precipitation: Days with .01, or more	Wind: Total movement	Wind: Prevailing direction	Wind: Maximum velocity: Miles per hour	Wind: Maximum velocity: Direction	Wind: Maximum velocity: Date	Clear days	Partly cloudy days	Cloudy days	Average cloudiness, tenths	Total snowfall	Snow, sleet, and ice on ground at end of month
	Ft.	°Ft.	°Ft.	In.	In.	In.	° F.	° F.	° F.		° F.	° F.		° F.	° F.	° F.	° F.		In.	In.		Miles.								0–10	In.	In.
Ohio Valley and Tennessee							**46.0**	**+0.8**										**74**	**3.54**	**0.0**										**7.0**		
Chattanooga	762	190	215	29.37	30.20	+0.06	51.0	+0.6	75	17	60	23	26	42	27	44	37	63	4.18	+0.8	6	5,608	nw.	27	nw.	22	10	8	12	5.3	0.0	0.0
Knoxville	995	102	111	29.11	30.19	+.06	48.6	+0.7	75	17	58	22	26	40	32	43	38	73	3.43	+0.4	7	4,096	sw.	25	s.	17	10	7	13	5.8	T.	0.0
Memphis	399	76	97	29.75	30.18	+.06	51.3	−0.4	80	16	59	28	26	44	26	46	41	73	4.06	−0.2	10	4,914	sw.	28	sw.	21	10	7	13	5.6	T.	0.0
Nashville	546	168	191	29.60	30.20	+.08	49.2	+0.2	73	17	57	21	26	41	26	43	38	69	2.63	−0.9	10	6,273	w.	34	s.	17	10	7	13	5.8	0.0	0.0
Lexington	989	193	230	29.08	30.18	+.06	44.9	+0.1	73	17	52	17	26	38	22				3.79	+0.3	16	8,821	sw.	38	sw.	21	7	7	16	6.5	0.4	0.0
Louisville	525	188	234	29.57	30.16	+.04	46.6	−0.1	74	17	54	21	26	39	24	42	37	73	2.94	−0.7	14	7,555	s.	31	s.	17	10	3	17	6.1	T.	0.0
Evansville	431	76	116	29.71	30.19	+.07	46.8	+0.2	71	16	54	22	26	40	28	42	37	74	3.13	−0.6	14	6,666	s.	35	sw.	17	12	2	16	5.9	T.	0.0
Indianapolis	822	194	230	29.22	30.12	+.02	43.4	+1.1	69	17	50	19	26	37	23	39	34	76	3.66	+0.3	17	8,257	s.	34	nw.	21	7	5	18	7.3	0.7	0.0
Royal Center	736	11	55	29.28	30.09		41.0		70	17	48	16	26	34	28				1.76		13	7,919	sw.	30	sw.	17	6	4	20	7.5	0.9	0.0
Terre Haute	575	96	129	29.49	30.12		44.2		69	17	51	19	26	37	24	40	35	76	2.08		18	6,642	s.	32	s.	17	10	2	18	6.8	0.1	0.0
Cincinnati	627	11	51	29.44	30.14	+.02	44.6	+2.1	75	17	52	19	26	37	34	40	36	78	3.25	+0.4	14	5,568	sw.	29	nw.	21	6	4	20	7.0	T.	0.0
Columbus	822	179	222	29.22	30.11	.00	44.0	+2.1	73	17	50	22	26	38	25	39	35	75	2.32	−0.4	15	7,301	nw.	36	nw.	21	2	7	21	7.9	T.	0.0
Dayton	899	137	173	29.14	30.12		43.7	+1.7	73	17	50	21	26	37	27	39	35	76	3.50	+0.6	15	6,900	sw.	36	nw.	21	3	6	21	8.0	0.5	0.0
Elkins	1,947	59	67	28.04	30.14	+.02	41.4	+1.1	74	17	51	16	26	32	46	38	34	81	3.98	+1.1	15	4,126	w.	30	w.	19	0	5	25	8.9	5.0	0.0
Parkersburg	637	77	82	29.47	30.14	+.02	45.2	+1.4	75	17	53	22	26	38	34	40	35	73	2.88	0.0	15	4,307	sw.	30	sw.	21	1	7	22	8.6	T.	0.0
Pittsburgh	842	353	410	29.16	30.08	−.02	43.9	+0.7	72	17	50	18	26	38	24	39	35	75	1.91	−0.4	17	7,774	w.	34	w.	30	0	7	23	8.3	1.4	0.0
Lower Lake Region							**42.1**	**+2.8**										**78**	**3.34**	**+0.5**										**8.0**		
Buffalo	767	247	280	29.14	29.98	−.07	41.4	+2.0	67	17	47	18	26	36	18	39	36	84	2.67	−0.4	15	12,399	sw.	58	w.	6	2	7	21	8.0	3.6	0.0
Canton	448	10	61	29.48	29.97		36.0	+2.1	65	15	43	15	27	29	25				3.83	+0.4	16	6,292	w.	39	nw.	6	5	7	18	7.4	4.8	T.
Ithaca	836	5	100	29.07	30.00		40.5		69	15	47	19	26	34	27	36	33	78	3.19	+0.8	17	5,882	nw.	33	nw.	6	3	7	20	7.6	10.2	0.0
Oswego	335	76	91	29.61	29.99	−.06	41.0	+2.1	70	15	47	20	26	35	21	38	35	79	3.76	+0.4	19	6,734	s.	34	w.	6	2	6	22	8.3	3.0	0.0
Rochester	523	86	102	29.42	30.01	−.05	41.8	+3.9	71	15	47	20	26	36	22	38	34	77	4.57	+2.0	17	5,516	w.	30	w.	19	2	5	23	8.3	9.2	0.0
Syracuse	596	65	97	29.38	30.03	−.03	42.0	+3.3	70	15	48	17	26	36	23				3.88	+1.2	16	4,579	w.	28	sw.	19	3	5	22	8.0	10.2	0.0
Erie	714	130	166	29.24	30.02	−.04	44.4	+3.0	70	17	49	25	25	39	22	39	35	73	3.88	+0.6	18	10,109	s.	36	sw.	21	3	4	23	8.3	5.9	0.0
Cleveland	762	190	201	29.21	30.05	−.02	44.2	+3.3	71	17	49	23	25	39	20	39	34	73	3.25	+0.6	18	10,139	sw.	44	nw.	12	2	4	24	8.4	1.2	0.0
Sandusky	629	5	67	29.37	30.07	−.01	44.0	+2.9	70	17	50	19	26	38	21				2.57	+0.2	14	7,292	sw.	28	w.	12	3	2	25	8.4	0.2	0.0
Toledo	628	208	243	29.37	30.06	−.01	43.2	+3.8	70	15	49	20	26	38	20	39	35	79	2.40	0.0	14	9,814	sw.	41	sw.	15	4	7	19	7.3	1.8	0.0
Fort Wayne	856	113	124	29.12	30.07		42.4	+1.8	70	17	49	20	26	36	22	38	35	79	2.67		16	7,074	sw.	29	n.	12	4	7	19	7.7	7.5	0.0
Detroit	730	218	258	29.23	30.04	−.02	42.4	+3.1	71	15	48	19	26	37	23	38	35	80	2.60	+0.2	11	7,521	sw.	38	sw.	15	2	8	20	8.0	1.0	0.0
Upper Lake Region							**37.6**	**+2.4**										**79**	**2.64**	**+0.2**										**7.7**		
Alpena	609	13	92	29.31	29.99	−.02	36.4	+2.0	60	15	42	19	25	31	28	34	30	80	3.06	+0.5	15	7,263	nw.	35	sw.	15	1	6	23	8.2	8.4	2.8
Escanaba	612	54	60	29.33	30.01	−.02	35.2	+2.1	56	6	41	16	25	30	27	32	28	76	0.55	−1.6	11	7,441	nw.	30	ne.	17	4	5	21	7.4	1.3	0.0
Grand Haven	632	54	89	29.32	30.02	−.02	40.5	+2.0	59	14	46	21	25	35	22	38	35	82	5.48	+2.8	18	8,903	n.	46	w.	6	3	5	22	8.2	7.3	0.0
Grand Rapids	707	70	87	29.25	30.03	−.02	40.8	+2.4	65	15	46	21	25	35	23	37	34	78	4.47	+1.7	16	4,291	nw.	23	nw.	21	2	8	20	8.4	3.5	0.0
Houghton	668	64	99	29.25	29.99	−.03	34.6	+2.6	58	14	40	17	25	29	24				0.72	−2.1	12	6,847	w.	40	w.	5	2	8	20	7.9	2.0	T.
Lansing	878	6	49	29.07	30.03		38.8	+1.3	66	15	44	19	25	33	28	37	35	89	4.07	+1.6	14	4,349	sw.	25	nw.	12	5	6	19	7.6	5.6	0.0
Ludington	637	60	66	29.30	30.01		39.2		56	14	44	22	25	34	21	37	34	82	4.39		18	8,295	n.	40	sw.	15	3	5	22	7.8	1.4	0.2
Marquette	734	77	111	29.18	30.00	−.02	35.3	+2.0	57	3	41	17	25	29	28	32	28	78	1.93	−1.0	16	7,185	w.	33	s.	23	3	2	25	8.5	6.8	T.
Port Huron	638	70	120	29.30	30.01	−.04	40.6	+3.1	70	15	46	20	25	35	23	37	34	80	2.54	+0.2	14	8,161	nw.	37	w.	15	3	9	18	7.4	3.2	0.0
Sault Sainte Marie	614	11	52	29.28	29.99	−.03	34.6	+2.6	52	15	40	14	25	29	27	32	28	79	1.12	−1.8	12	6,097	nw.	36	nw.	6	2	5	23	8.8	3.5	T.
Chicago	673	7	131	29.33	30.06	−.01	42.2	+2.1	68	15	48	20	25	37	21	38	34	75	4.00	+1.6	14	8,297	sw.	29	s.	14	7	4	19	7.0	T.	0.0
Green Bay	617	109	141	29.35	30.02	−.02	37.0	+3.0	58	14	42	17	25	32	22	33	29	75	1.18	−0.8	7	8,216	s.	42	sw.	15	5	7	18	7.5	1.1	0.4
Milwaukee	681	125	221	29.29	30.04	−.01	40.0	+2.7	64	15	45	19	25	34	22	36	32	76	4.88	+3.1	10	10,591	w.	44	sw.	14	6	6	18	7.3	1.2	0.0
Duluth	1,133	5	47	28.78	30.03	−.01	33.4	+3.4	57	13	40	10	25	26	27	29	25	76	0.30	−1.2	3	7,824	w.	34	nw.	21	7	7	16	6.7	T.	0.0
North Dakota							**31.8**	**+4.9**										**76**	**0.52**	**−0.2**										**4.9**		
Moorhead	940	50	58	29.02	30.07	.00	32.0	+4.9	58	13	41	8	25	23	27	28	25	79	0.30	−0.6	3	5,318	nw.	27	nw.	21	9	10	11	5.9	0.1	0.0
Bismarck	1,674	8	57	28.28	30.10	+.03	32.6	+4.1	64	10	44	4	25	21	42	28	23	74	0.07	−0.5	3	4,729	nw.	35	nw.	21	14	8	8	4.9	0.6	0.0
Devils Lake	1,478	11	44	28.44	30.06	.00	30.0	+5.5	54	10	40	6	1	20	33	26	22	80	1.73	+1.0	2	5,870	w.	28	nw.	21	14	7	9	4.7	T.	0.0
Ellendale	1,457	10	56	28.50	30.10		32.6		58	13	43	9	25	22	38				1.01		4	8,243	nw.	45	nw.	21	12	6	12	5.3	0.4	0.0
Grand Forks	833	12	67				31.0		57	13	41	9	25	21	33	27			1.13		2		nw.		nw.	15	5	11	14		T.	0.0
Williston	1,878	41	48	28.06	30.09	+.03	32.4	+5.2	59	4	44	7	2	21	37	27	21	69	T.	−0.6	0	4,026	sw.	28	nw.	21	16	9	5	3.7	T.	0.0
Upper Mississippi Valley							**40.8**	**+2.3**										**78**	**3.03**	**+1.4**										**6.4**		
Minneapolis	918	102	208	29.03	30.04		36.4	+4.0	59	13	43	15	25	30	23				0.35	−0.9	4	7,775	nw.	35	nw.	21	7	8	15	6.8	T.	0.0
St. Paul	837	236	261	29.13	30.06	.00	35.8	+3.3	57	13	42	15	25	29	24				0.21	−1.1	4	8,009	nw.	45	w.	15	7	8	15	6.5	0.3	0.0
La Crosse	714	11	48	29.27	30.06	−.01	38.2	+3.0	61	14	45	16	25	32	27	34	30	77	1.64	+0.1	7	3,884	nw.	26	sw.	15	7	6	17	6.9	1.8	0.0
Madison	974	70	78	28.99	30.07	+.01	37.5	+2.3	60	14	43	17	25	32	22	34	31	79	4.80	+3.1	10	7,458	nw.	32	s.	14	7	5	18	7.0	5.9	5.2
Wausau	1,247	4	64		30.04		34.8		55	5	40	15	25	30	22				0.61		6		nw.				5	2	23		2.5	T.
Charles City	1,015	10	51	28.98	30.09	+.01	36.3	+3.3	60	11	43	16	25	30	26	33	30	82	3.47	+2.1	8	4,942	nw.	27	sw.	14	13	2	15	6.1	2.4	0.0
Davenport	606	71	79	29.41	30.08	.00	41.4	+2.4	67	15	48	17	25	35	26	37	33	78	4.29	+2.5	13	5,258	nw.	26	s.	14	9	4	17	6.6	0.6	0.0
Des Moines	861	84	97	29.16	30.09	+.01	40.4	+2.0	67	15	48	17	25	33	26	37	33	78	4.62	+3.2	10	5,317	sw.	37	sw.	14	11	5	14	6.3	8.4	7.3
Dubuque	700	81	96	29.30	30.09	.00	39.2	+2.2	64	15	45	17	25	33	25	35	31	76	4.88	+3.2	12	5,038	nw.	24	nw.	21	8	5	17	6.9	4.5	4.4
Keokuk	614	64	78	29.42	30.11	+.02	42.9	+1.8	69	15	50	20	25	36	26	38	34	76	5.18	+3.2	10	5,479	s.	31	s.	14	10	4	16	6.3	0.3	0.0
Cairo	358	87	93	29.78	30.17	+.05	47.7	+0.4	70	15	55	26	26	40	28	43	38	72	3.30	−0.4	12	6,125	s.	32	sw.	17	9	5	16	6.1	0.0	0.0
Peoria	609	11	45	29.43	30.10	+.01	41.7	+4.2	66	15	48	18	25	35	26	38	35	82	3.97	+1.6	15	5,052	nw.	24	sw.	17	9	5	16	6.0	T.	0.0
Springfield, Ill.	636	10	91	29.41	30.10	.00	43.0	+0.8	67	15	50	19	25	36	26	40	38	86	1.79	−0.7	9	8,957	nw.	37	nw.	21	8	6	16	6.4	T.	0.0
Hannibal	534	74	109	29.52	30.10	+.01	44.2	+2.1	70	15	51	21	25	37	29				3.82	+1.9	11	6,263	sw.	30	s.	14	11	5	14	6.0	T.	0.0
St. Louis	568	265	303	29.51	30.13	+.03	46.0	+0.9	70	11	53	23	25	39	32	41	36	72	1.90	−0.9	12	9,394	sw.	41	sw.	14	12	3	15	5.7	T.	0.0
Missouri Valley							**40.4**	**+1.4**										**75**	**3.40**	**+2.2**										**5.4**		
Columbia, Mo.	784	6	84	29.27	30.12	+.03	44.5	+1.2	70	15	52	19	25	36	34				4.68	+2.4	12	5,535	s.	35	nw.	16	12	3	15	5.8	0.3	0.0
Kansas City	963	161	181	29.07	30.13	+.04	45.2	+1.5	74	15	53	21	25	37	25	40	34	71	8.55	+6.7	10	7,260	s.	30	sw.	14	14	5	14	5.2	0.6	0.0
St. Joseph	967	11	49	29.05	30.11		43.6		73	15	51	18	25	35	30	38	34	74	6.98		8	6,056	nw.	29	sw.	14	15	4	11	4.9	0.1	0.0
Springfield, Mo.	1,324	98	104	28.73	30.16	+.06	45.4	−0.3	68	14	53	22	25	38	30	40	35	75	2.08	−0.6	9	7,240	s.	29	s.	15	14	2	14	5.3	1.6	0.0
Iola	984	11	50	29.06	30.13	+.04	44.8	+0.5	72	14	54	22	25	35	32				9.01	+7.6	11	4,297	s.	20	sw.	14	11	5	14	5.8	T.	0.0
Topeka	987	92	107				44.0	+1.2	73	15	53	20	25	35	28				6.08	+4.8	11	6,932	sw.	29	sw.	14	13	7	10	4.9	0.1	0.0
Lincoln	1,180	11	81	28.82	30.12	+.04	40.2	+1.1	66	15	48	16	25	33	29	35	31	76	2.87	+2.0	7	7,029	s.	34	w.	14	8	6	16	6.1	12.2	4.5
Omaha	1,105	115	122	28.90	30.12	+.03	40.6	+2.1	67	15	48	18	25	32	30	36	31	73	2.87	+1.8	8	6,088	nw.	28	n.	17	12	9	9	4.9	15.8	6.1
Valentine	2,598	47	54	27.36	30.15	+.07	35.4	+0.8	66	10	45	8	3	25	37	30	26	74	0.69	0.0	5	5,189	w.	31	s.	12	11	6	13	5.4	5.7	0.0
Sioux City	1,135	94	164	28.88	30.12	+.04	37.4	+2.2	63	13	44	15	25	30	27	33	30	76	0.88	−0.1	5	8,303	nw.	45	sw.	14	10	10	10	5.5	6.3	0.0
Huron	1,306	59	74	28.69	30.13	+.05	34.4	+2.9	61	13	43	11	25	26	33	30	26	78	1.07	+0.5	4	5,962	nw.	42	nw.	14	10	11	9	5.1	2.2	0.0
Pierre	1,572	70	75		30.14	+.06	36.1	+2.5	68	13	45	11	3	27	35				0.62	+0.2	5	4,508	nw.	32	nw.	24	12	9	9		2.0	0.0
Yankton	1,233	49	57	28.77	30.12	+.04	36.6	+1.3	64	13	44	13	25	29	27				1.44	+0.6	3	5,360	nw.	29	w.	14	7	10	13	6.1	12.0	0.0

TABLE I.—*Climatological data for Weather Bureau stations, November, 1928*—Continued

District and station	Elevation of instruments: Barometer above sea level	Elevation of instruments: Thermometer above ground	Elevation of instruments: Anemometer above ground	Pressure: Station reduced to mean of 24 hours	Pressure: Sea level, reduced to mean of 24 hours	Pressure: Departure from normal	Temperature of the air: Mean max. + mean min. ÷ 2	Temperature: Departure from normal	Temperature: Maximum	Temperature: Date	Temperature: Mean maximum	Temperature: Minimum	Temperature: Date	Temperature: Mean minimum	Temperature: Greatest daily range	Mean wet thermometer	Mean temperature of the dew-point	Mean relative humidity	Precipitation: Total	Precipitation: Departure from normal	Precipitation: Days with .01, or more	Wind: Total movement	Wind: Prevailing direction	Wind: Maximum velocity: Miles per hour	Wind: Maximum velocity: Direction	Wind: Maximum velocity: Date	Clear days	Partly cloudy days	Cloudy days	Average cloudiness, tenths	Total snowfall	Snow, sleet, and ice on ground at end of month
	Ft.	Ft.	Ft.	In.	In.	In.	°F.	°F	°F.		°F.	°F.		°F.	°F.	°F.	°F.	%	In.	In.		Miles								0-10	In.	In.
Northern Slope							34.0	+1.3										71	0.77	0.0										5.4		
Billings	3,140	5					35.4		67	10	48	8	29	23	47				0.41		5		nw.				20	4	6			
Harve	2,505	11	44	27.41	30.12	+0.09	33.6	+2.4	68	12	48	4	19	19	48	27	20	66	0.02	−0.6	1	3,848	sw.	28	sw.	9	14	8	8	4.3	0.4	0.0
Helena	4,110	87	112	25.86	30.15	+.05	36.4	+3.2	60	21	45	13	2	28	26	30	23	63	0.02	−0.7	1	4,799	sw.	30	sw.	10	6	13	11	6.1	0.5	0.0
Kalispell	2,973	48	56	27.02	30.15	+.08	34.4	+2.0	58	21	42	15	1	27	27	31	27	80	0.50	−1.4	5	2,493	nw.	20	sw.	10	7	5	18	6.8	0.5	T.
Miles City	2,371	48	55	27.55	30.17	+.10	35.8	+4.9	63	22	48	10	29	24	38	29	23	65	0.26	−0.3	2	3,068	s.	21	nw.	5	14	7	9	4.3	1.6	0.6
Rapid City	3,259	50	58	26.67	30.17	+.09	37.8	+1.9	72	13	48	14	2	27	42	31	24	62	0.78	+0.3	5	4,251	w.	30	nw.	14	11	10	9	4.9	3.1	0.0
Cheyenne	6,088	84	101	24.04	30.15	+.08	34.4	−0.4	64	10	45	7	2	24	35	28	22	65	1.19	+0.7	7	7,256	w.	54	nw.	14	11	5	14	5.8	14.6	8.0
Lander	5,372	60	68	24.71	30.23	+.13	27.4	−2.9	63	10	38	−7	30	17	38	24	22	86	2.55	+2.0	5	1,973	n.	28	w.	12	14	6	10	4.9	26.2	16.5
Sheridan	3,790	10	47	26.16	30.18		32.2		69	10	45	−2	29	20	39	27	22	76	1.12		7	2,163	nw.	17	nw.	14	12	13	5	4.6	10.8	5.5
Yellowstone Park	6,241	11	48	23.95	30.24	+.13	29.1	−0.2	53	12	38	0	18	20	30	25	20	73	0.59	−0.8	8	4,750	sw.	32	sw.	9	6	6	18	6.9	8.0	1.8
North Platte	2,821	11	51	27.15	30.15	+.07	37.0	+0.4	72	10	48	11	3	26	39	31	26	72	0.99	+0.5	7	4,474	n.	28	nw.	14	14	4	12	5.1	9.5	5.8
Middle Slope							42.4	−0.4										72	2.84	+1.8										5.0		
Denver	5,292	106	113	24.78	30.14	+.08	39.6	−0.2	72	12	50	10	2	29	36	32	24	60	1.58	+1.0	6	4,462	s.	28	w.	14	12	10	8	4.7	23.1	8.2
Pueblo	4,685	80	86	25.36	30.15	+.10	37.3	−2.1	73	10	51	−1	19	24	44	31	24	64	1.19	+0.8	6	3,376	nw.	44	nw.	14	13	13	4	3.9	11.3	3.3
Concordia	1,392	50	58	28.65	30.16	+.08	42.2	+0.8	69	15	51	20	25	33	31	37	33	76	2.59	+1.6	8	5,274	s.	30	w.	14	10	7	13	5.7	2.6	T.
Dodge City	2,509	11	51	27.51	30.17	+.10	42.6	0.0	70	15	54	20	3	32	36	36	33	78	2.35	+1.6	9	6,187	s.	31	s.	13	10	4	7	3.5	T.	0.0
Wichita	1,358	139	158	28.67	30.13	+.05	44.9	+0.1	69	15	54	25	25	36	33	40	37	78	5.45	+4.3	10	8,381	s.	40	s.	14	13	7	10	5.2	0.9	0.0
Broken Arrow	765	11	56	29.32	30.16		47.2		75	14	56	23	26	38	33				2.41		12	7,800	s.	32	sw.	14	7	9	14	6.2	T.	0.0
Oklahoma City	1,214	10	47	28.85	30.16	+.08	47.8	−1.0	76	15	57	28	3	39	31	42	38	76	3.88	+1.6	9	6,296	s.	25	s.	13	11	4	15	6.0	0.1	0.0
Southern Slope							50.0	−1.7										72	1.18	0.0										4.7		
Abilene	1,738	10	52	28.33	30.17	+.10	52.0	−1.5	77	14	62	26	20	42	35	45	40	72	0.49	−0.9	7	5,590	s.	28	s.	16	11	6	13	5.7	0.0	0.0
Amarillo	3,676	10	49	26.35	30.14	+.09	44.2	−1.3	69	10	54	20	19	34	31	38	34	77	3.54	+2.4	5	5,684	sw.	24	se.	18	17	7	6	3.8	13.9	0.0
Del Rio	944	64	71	29.13	30.13	+.08	57.7	−2.3	83	7	67	33	20	49	35	51	45	69	0.38	−0.8	5	4,545	se.	31	n.	16	11	7	12	5.4	0.0	0.0
Roswell	3,566	75	85	26.47	30.13	+.10	46.3	−1.8	71	15	58	20	19	35	39	39	34	70	0.31	−0.6	3	4,204	s.	34	nw.	18	16	9	5	3.9	T.	0.0
Southern Plateau							49.2	−0.2										58	0.40	−0.1										3.4		
El Paso	3,778	152	175	26.28	30.11	+.11	51.4	−1.3	75	15	62	28	19	41	32	42	34	58	0.79	+0.3	4	5,737	e.	35	w.	16	18	7	5	3.3	0.0	0.0
Santa Fe	7,013	38	53	23.29	30.13	−.10	37.4	−1.5	65	11	47	16	30	27	34	31	25	68	0.58	−0.1	7	3,610	n.	25	n.	8	13	5	12	4.9	2.7	0.0
Flagstaff	6,907	10	59	23.39	30.07	+.05	35.7	+0.3	68	11	48	7	18	24	42	30		75	1.82		8		e.				13	12	5		2.0	T.
Phoenix	1,108	10	82	28.86	30.03	+.05	60.2	+0.5	84	11	74	33	30	47	36	48	38	50	0.16	−0.8	2	2,127	e.	20	sw.	13	15	12	3	3.6	0.0	0.0
Yuma	141	9	54	29.88	30.03	+.05	62.2	−0.2	83	10	76	38	29	49	34	49	35	41	0.04	−0.2	2	3,426	n.	22	w.	13	26	1	3	1.9	0.0	0.0
Independence	3,957	6	27	26.30	30.13	+.08	48.3	+1.1	79	6	63	22	30	34	38	34			0.43	+0.1	1		nw.				20	6	4		0.0	0.0
Middle Plateau							39.4	+0.1										62	0.82	0.0										4.8		
Reno	4,532	74	81	25.55	30.14	+.03	42.2	+1.2	72	5	56	16	29	28	42	34	25	57	0.29	−0.4	5	3,372	w.	30	w.	6	15	12	3	4.0	0.7	0.0
Tonopah	6,090	12	20				38.9		65	5	46	17	18	32	25	31	20	46	0.27		3		se.									
Winnemucca	4,344	18	56	25.73	30.20	+.06	37.3	−1.1	64	5	51	9	29	24	39	32	26	68	0.64	0.0	8	3,834	ne.	29	nw.	16	10	15	5	4.2	1.4	1.0
Modena	5,473	10	43	24.69	30.12	+.04	36.8	+0.4	66	11	50	8	29	23	44	30	23	63	0.22	−0.4	4	5,825	sw.	38	sw.	13	14	10	6	4.3	0.2	0.0
Salt Lake City	4,360	163	203	25.72	30.16	+.04	40.5	−0.6	63	12	47	18	18	34	22	35	29	67	1.86	+0.5	12	[illegible],600	nw.	30	s.	6	6	2	12	6.3	6.1	T.
Grand Junction	4,602	60	68	25.48	30.12	+.04	40.1	+0.8	61	7	49	24	19	31	31	34	30	71	1.09	+0.5	10	3,084	se.	36	sw.	13	11	8	11	5.4	4.5	0.7
Northern Plateau							39.8	+0.4										74	0.81	−0.6										7.2		
Baker	3,471	48	53	26.56	30.20	+.04	37.2	+1.2	56	11	45	17	18	29	24	34	29	72	0.40	−0.8	9	3,512	se.	21	s.	10	6	10	14	6.7	0.7	T.
Boise	2,739	78	86	27.30	30.21	+.04	41.8	+0.8	67	11	50	21	18	33	27	36	30	68	0.76	−0.5	8	3,014	se.	21	se.	11	5	10	15	6.7	T.	T.
Lewiston	757	40	48	29.35	30.18	+.06	41.8	+0.4	64	10	50	24	2	34	34				0.39	−0.9	10	1,643	e.	18	nw.	10	3	8	19	7.6	T.	0.0
Pocatello	4,477	60	68	25.57	30.17	+.03	37.8	+1.1	62	12	45	12	18	30	26	33	28	70	1.34	+0.8	8	4,607	se.	26	s.	12	4	12	14	6.7	6.3	3.0
Spokane	1,929	101	110	28.09	30.19	+.09	37.6	−0.9	53	10	44	22	2	31	28	35	32	81	1.24	−0.8	11	2,296	nw.	28	sw.	10	5	3	22	7.9	0.9	T.
Walla Walla	991	57	65	29.08	30.17	+.04	42.8	0.0	64	9	49	28	10	36	23	30	36	80	0.75	−1.3	11	2,108	s.	19	se.	8	5	5	20	7.3	T.	0.0
North Pacific Coast Region							47.6	+1.2										84	4.30	−2.3										7.9		
North Head	211	11	56	29.85	30.08	+.03	48.4	+0.2	62	21	53	38	17	44	16	47	45	90	6.32	−1.1	16	10,441	se.	58	s.	8	4	6	20	8.0	0.0	0.0
Port Angeles	29	8	53		30.06		44.6		57	4	50	33	18	39	17				1.92	−2.5	13	3,329	sw.	26	sw	30	1	7	22		0.0	0.0
Seattle	125	215	250	29.96	30.09	+.05	46.8	+1.2	63	2	51	34	18	42	16	44	41	80	2.29	−3.0	17	4,801	se	32	s.	10	1	5	24	8.6	0.0	0.0
Tacoma	194	172	201	29.88	30.10	+.06	46.4	+1.8	64	20	52	31	18	41	21				2.68	−3.9	15	4,273	s.	32	sw.	30	0	6	24	8.9	0.0	0.0
Tatoosh Island	86	9	53	29.94	30.03	+.06	48.4	+2.5	62	2	51	41	30	46	12	47	46	92	9.04	−3.0	23	11,912	e.	51	s.	15	4	5	21	7.9	0.0	0.0
Yakima	1,071	5					40.1		61	4	50	22	19	30	32	36		80	0.62		7		se.				9	6	15	6.2	0.0	0.0
Medford	1,425	4	80	28.60	30.14		44.4		70	9	54	23	24	35	35	41	38	82	1.11		14		w.	30	se.	2	5	5	20	7.3	0.3	T.
Portland, Oreg.	153	68	106	29.96	30.12	+.02	46.6	−0.2	61	4	52	31	18	41	21	44	41	82	5.30	−0.8	16	3,147	se.	19	nw.	16	2	2	26	8.5	0.0	0.0
Roseburg	510	75	99	29.56	30.12	.00	47.6	+1.7	71	2	55	32	19	40	24	44	41	82	2.54	−2.1	15	2,149	s.	25	w.	11	4	8	18	7.7	0.0	0.0
Middle Pacific Coast Region							53.1	−0.6										76	3.89	+1.1										4.7		
Eureka	62	73	89	30.07	30.14	+.03	51.4	+0.3	71	2	58	35	17	44	23	48	45	82	4.90	−0.3	15	3,921	se.	27	se.	2	7	6	17	6.7	0.0	0.0
Red Bluff	330	54	58	29.77	30.13	+.02	51.7	−2.1	77	20	62	33	30	42	6	47	42	72	5.75	+2.8	7	3,370	nw.	33	se.	13	9	10	11	5.4	0.0	0.0
Sacramento	69	106	117	30.05	30.12	+.03	53.0	−0.6	70	1	62	36	29	44	27	49	45	76	2.98	+1.1	6	3,981	se.	32	se.	13	19	6	5	2.9	0.0	0.0
San Francisco	155	208	243	29.96	30.13	+.04	56.4	+0.1	70	1	63	45	30	50	19	51	46	74	3.35	+1.0	6	4,034	w.	30	s.	13	13	10	7	4.6	0.0	0.0
San Jose	141	12	110	29.98	30.13		53.5		74	1	65	33	30	42	33				2.47	+1.0	5	3,402	nw.	26	se.	13	15	11	4	3.8	0.0	0.0
South Pacific Coast Region							59.1	+0.9										64	1.29	+0.3										3.4		
Fresno	327	89	98	29.77	30.14	+.08	54.0	−0.2	75	2	65	35	28	43	30	48	43	71	1.57	+0.6	4	2,561	nw.	17	se.	14	19	7	4	3.0	0.0	0.0
Los Angeles	338	159	191	29.71	30.07	+.05	63.2	+2.3	85	20	72	49	15	54	28	51	41	54	1.67	+0.5	3	3,100	ne.	18	w.	12	17	6	7	3.5	0.0	0.0
San Diego	87	62	70	29.96	30.05	+.02	60.2	+0.5	83	20	68	45	30	52	32	53	47	67	0.63	−0.1	5	3,218	nw.	23	s.	14	13	11	6	3.8	0.0	0.0
West Indies																																
Juan, P. R.	82	9	54	29.83	29.91		78.9	+0.5	88	20	84	72	27	74	15				8.21	+1.3	24	6,154	e.	34	e.	15	5	21	4	5.4	0.0	0.0
Panama Canal																																
Balboa Heights	118	7	97	[1]29.75	[2]29.84	.00	78.4	−0.7	88	21	84	70	7	73	15	74	74	[2]90	20.51	+10.3	23	[3]3,824	nw.	[3]25	s.	5	0	5	25	8.7	0.0	0.0
Colon	38	7	97	[1]29.83	[2]29.83	−.02	79.8	+0.5	91	16	85	72	12	75	16	67	75	[2]88	17.20	−4.2	30	[3]5,330	s.	[3]32	sw.	26	0	5	25	8.7	0.0	0.0
Alaska																																
Juneau	80	11	50	[4]29.65	[4]29.74		38.8		58	2	43	22	13	35	19	37	34	82	9.02		23	6,721	e.	40	se.	3	5	0	25	8.2	4.2	T.
Hawaiian Islands																																
Honolulu	38	86	100	[4]30.01	[4]30.05		74.6		83	3	79	66	22	70	14	68	65	75	2.37	−1.5	17	5,591	e.	36	e.	4	9	6	15	6.3	0.0	0.0

[1] 8 a. m. observation only. [2] Observations taken bihourly. [3] 4-cup anemometer. [4] Pressure not reduced to mean of 24 hours.

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TABLE 2.—*Data furnished by the Canadian Meteorological Service, November, 1928*

Station	Altitude above mean sea level, Jan. 1, 1919	Pressure: Station reduced to mean of 24 hours	Pressure: Sea level reduced to mean of 24 hours	Pressure: Departure from normal	Temperature of the air: Mean max. + mean min. ÷ 2	Temperature of the air: Departure from normal	Temperature of the air: Mean maximum	Temperature of the air: Mean minimum	Temperature of the air: Highest	Temperature of the air: Lowest	Precipitation: Total	Precipitation: Departure from normal	Precipitation: Total snowfall
	Feet	Inches	Inches	Inches	°F.	°F.	°F.	°F.	°F.	°F.	Inches	Inches	Inches
Cape Race, N. F.	99				39.3		49.5	29.2	55	16	11.60		0.2
Sydney, C. B. I.	48												
Halifax, N. S.	88												
Yarmouth, N. S.	65												
Charlottetown, P. E. I.	38												
Chatham, N. B.	28												
Father Point, Que.	20												
Quebec, Que.	296	29.60	29.94	−0.08	29.3	+0.3	34.0	24.7	48	6	2.86	−0.90	6.3
Doucet, Que.	1,236				23.3		30.6	16.0	47	−7	0.59		1.1
Montreal, Que.	187	29.72	29.94	−.09	34.8	+3.0	40.3	29.2	62	15	3.97	+0.23	11.8
Ottawa, Ont.	236	29.70	29.98	−.04	34.3	+2.6	40.8	27.7	64	12	2.69	+0.15	7.4
Kingston, Ont.	285	29.66	29.98	−.06	38.3	+3.3	44.0	32.6	60	12	3.40	+0.16	1.9
Toronto, Ont.	379	29.57	29.99	−.05	39.7	+4.1	45.2	34.2	65	16	4.22	+1.08	0.9
Cochrane, Ont.	930				25.4		30.7	20.2	47	5	2.12		14.3
White River, Ont.	1,244	28.59	29.94	−.04	24.8	+4.3	33.1	16.5	48	−7	1.01	−0.84	3.1
London, Ont.	808				39.2		44.5	34.0	66	15	5.11		11.6
Southampton, Ont.	656	29.24	29.97	−.05	38.1	+3.1	43.7	32.5	60	17	5.73	+2.03	8.0
Parry Sound, Ont.	688	29.27	29.98	−.03	33.8	+1.7	39.5	28.1	52	10	4.96	+0.59	14.7
Port Arthur, Ont.	644	29.28	30.01	+.01	32.6	+8.6	39.5	25.7	53	7	0.82	−0.51	0.4
Winnipeg, Man.	760	29.17	30.04	.00	30.3	+12.3	36.9	23.8	55	8	1.66	+0.58	T.
Minnedosa, Man.	1,690	28.16	30.03	−.01	27.3	+10.0	36.3	18.3	52	4	0.15	−0.85	T.
Le Pas, Man.	860				24.9		32.9	16.9	43	0	0.05		0.5
Qu'Appelle, Sask.	2,115	27.73	30.03	+.03	28.9	+10.1	39.1	18.8	52	4	0.03	−0.86	T.
Moose Jaw, Sask.	1,759												
Swift Current, Sask.	2,392	27.42	29.99	−.03	33.1	+9.9	47.0	19.2	64	2	T.	−0.69	T.
Medicine Hat, Alb.	2,144												
Calgary, Alb.	3,428												
Banff, Alb.	4,521												
Prince Albert, Sask.	1,450	28.40	30.01	−.02	28.0	+12.6	37.3	18.7	48	6	0.04	−0.79	0.3
Battleford, Sask.	1,592	28.22	30.00	−.02	28.6	+12.3	40.3	17.0	56	6	T.	−0.58	T.
Edmonton, Alb.	2,150												
Kamloops, B. C.	1,262												
Victoria, B. C.	230	29.81	30.07	+.08	46.4	+3.2	49.9	43.0	59	38	1.91	−5.06	0.0
Barkerville, B. C.	4,180												
Estevan Point, B. C.	20												
Prince Rupert, B. C.	170												
Hamilton, Ber.	151	29.99	30.15	+.10	67.4	−1.3	73.9	60.9	81	49	7.06	+2.68	0.0

LATE REPORTS FOR OCTOBER, 1928

Station	Altitude	Station pressure	Sea level pressure	Departure	Mean	Departure	Mean maximum	Mean minimum	Highest	Lowest	Total	Departure	Total snowfall
Father Point, Que.	20	29.93	29.95	.00	41.3	+1.5	47.3	35.4	67	24	3.96	+1.06	0.0
Southampton, Ont.	656				50.1	+4.0	58.4	41.9	80	25	5.53	+2.36	2.5
Winnipeg, Man.	760	29.17	30.02	+.04	41.2	+2.1	50.0	32.5	68	16	0.42	−1.28	0.9
Medicine Hat, Alb.	2,144	27.67	29.95	−.02	41.6	−3.2	53.0	30.2	68	18	0.40	−0.18	0.0
Calgary, Alb.	3,428	26.42	30.04	+.00	38.0	−2.1	50.7	25.4	71	3	0.54	+0.06	3.0
Banff, Alb.	4,521	25.39	30.02	+.07	36.0	−3.3	45.0	27.0	55	13	0.98	−0.04	1.6
Kamloops, B. C.	1,262	28.73	30.04	+.08	45.0	−2.0	53.5	36.5	68	25	0.16	−0.45	0.0
Barkerville, B. C.	4,180	25.62	29.95	+.01	34.5	−5.2	41.8	27.3	50	14	3.41	+0.71	19.3
Estevan Point, B. C.	20				49.8		55.4	44.2	62	35	14.08		0.0
Prince Rupert, B. C.	170				46.9		52.3	41.6	60	30	9.63		0.0

Chart I. Departure (°F.) of the Mean Temperature from the Normal, November, 1928

Chart II. Tracks of Centers of Anticyclones, November, 1928. (Inset) Departure of Monthly Mean Pressure from Normal

(Plotted by Wilfred P. Day)

Chart III. Tracks of Centers of Cyclones, November, 1928. (Inset) Change in Mean Pressure from Preceding Month
(Plotted by Wilfred P. Day)

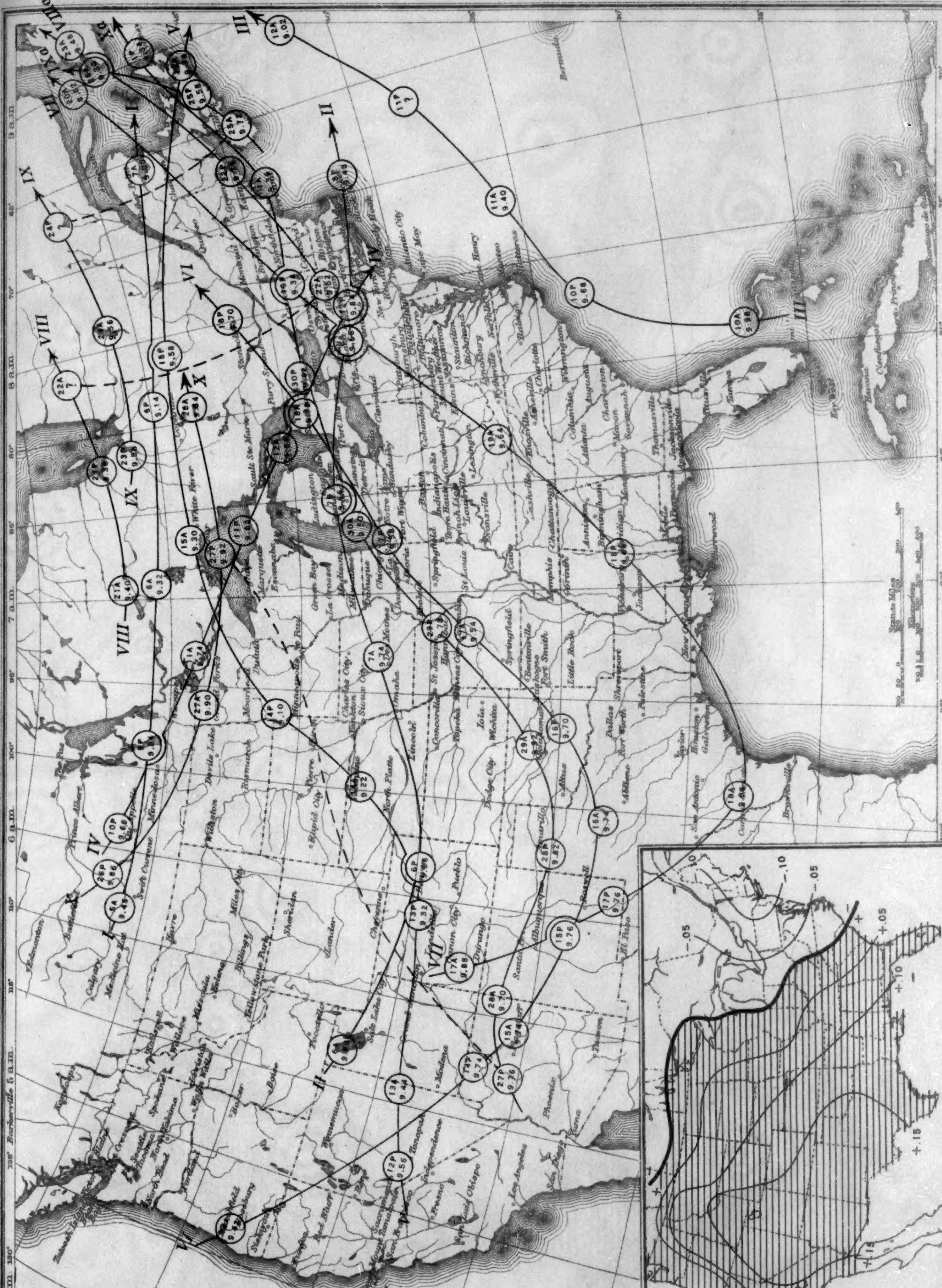


Chart IV. Percentage of Clear Sky between Sunrise and Sunset, November, 1928

Chart V. Total Precipitation, Inches, November, 1928. (Inset) Departure of Precipitation from Normal

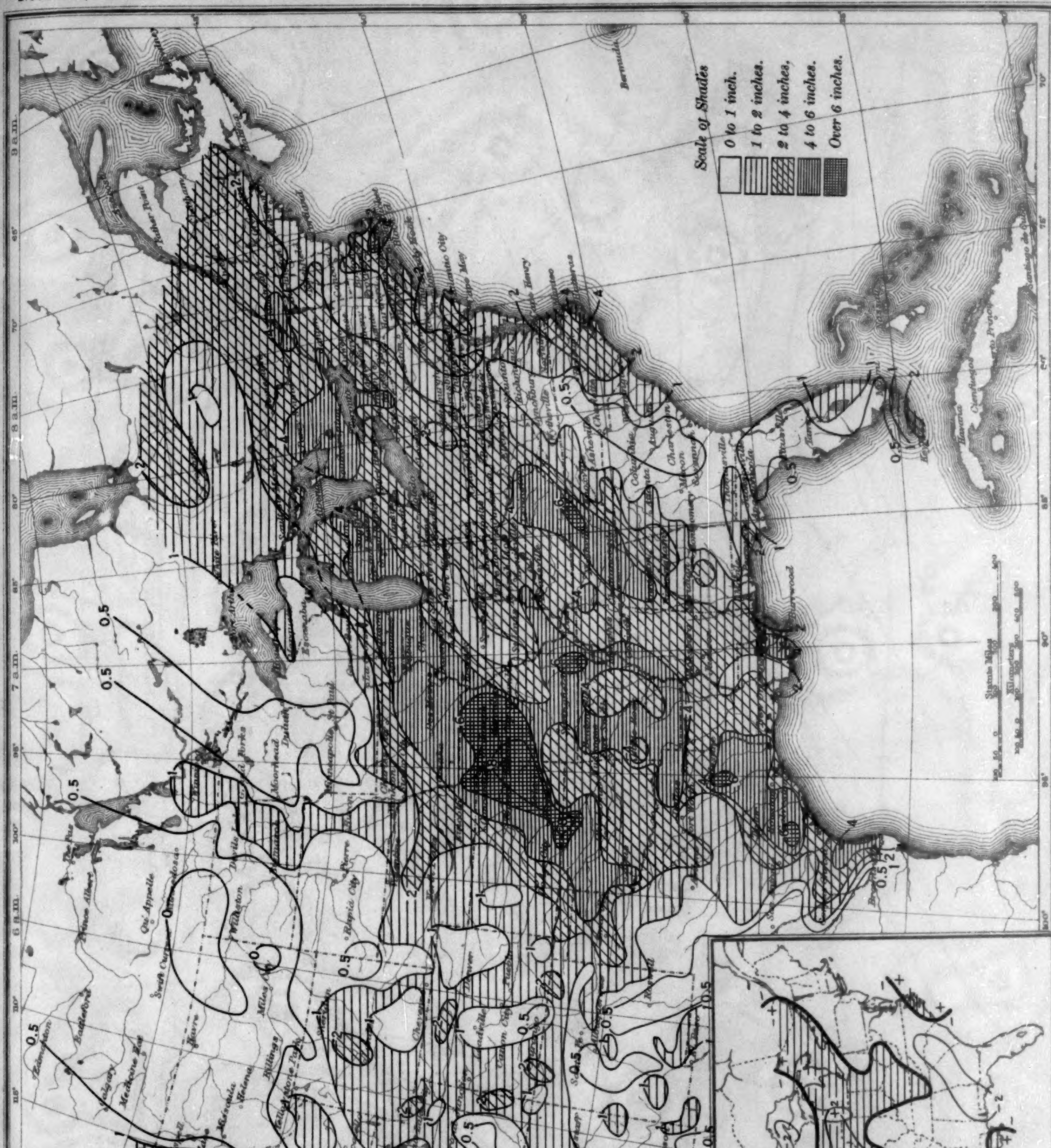


Chart VI. Isobars at Sea level and Isotherms at Surface; Prevailing Winds, November, 1928

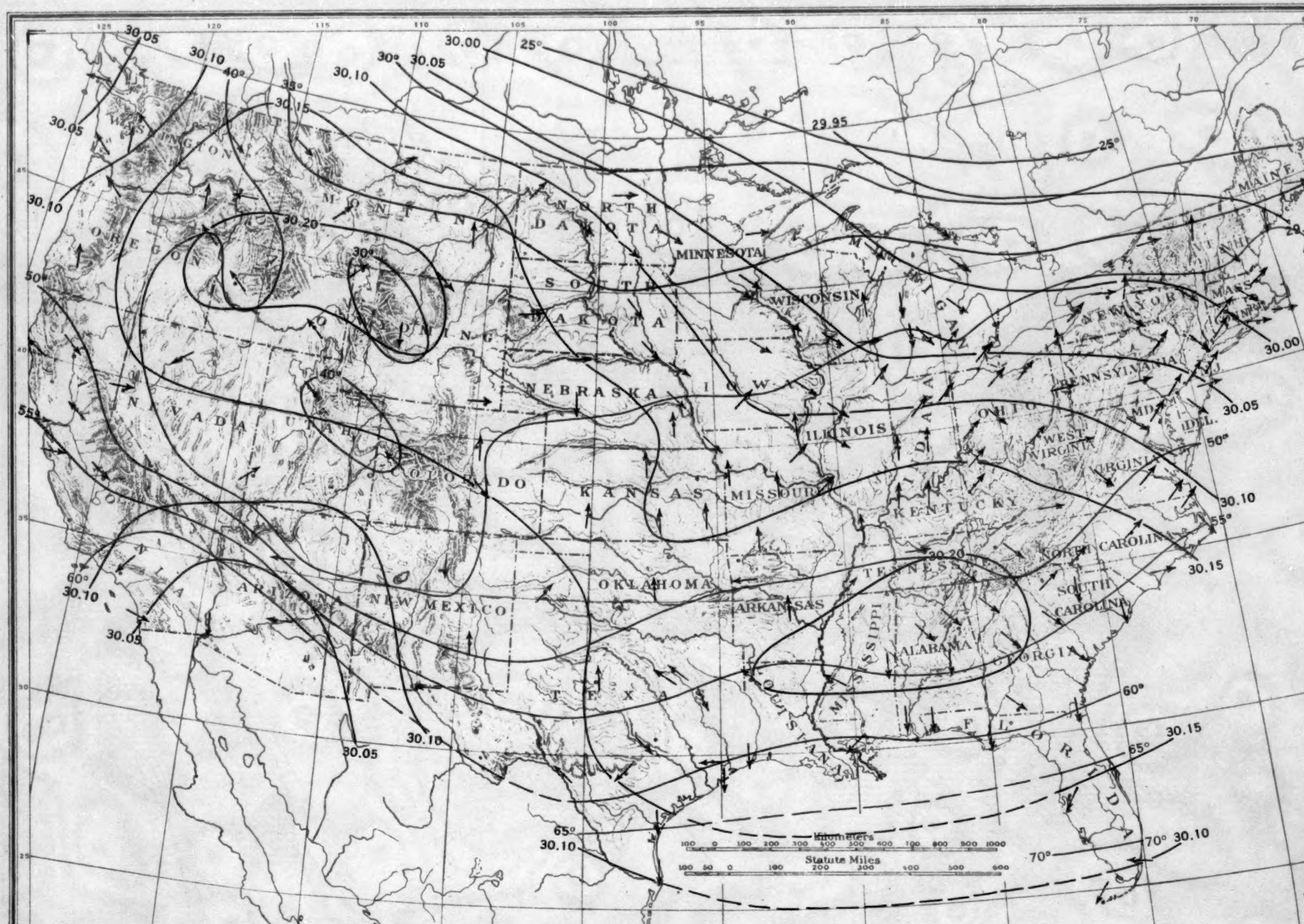


Chart VII. Total Snowfall, Inches, November, 1928.

Chart VII. Total Snowfall, Inches, November, 1928.

Chart VIII. Weather Map of North Atlantic Ocean, October 29, 1928
(Plotted by F. A. Young)

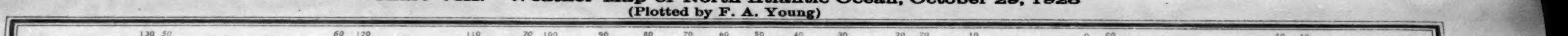


Chart VIII. Weather Map of North Atlantic Ocean, October 29, 1928

(Plotted by F. A. Young)

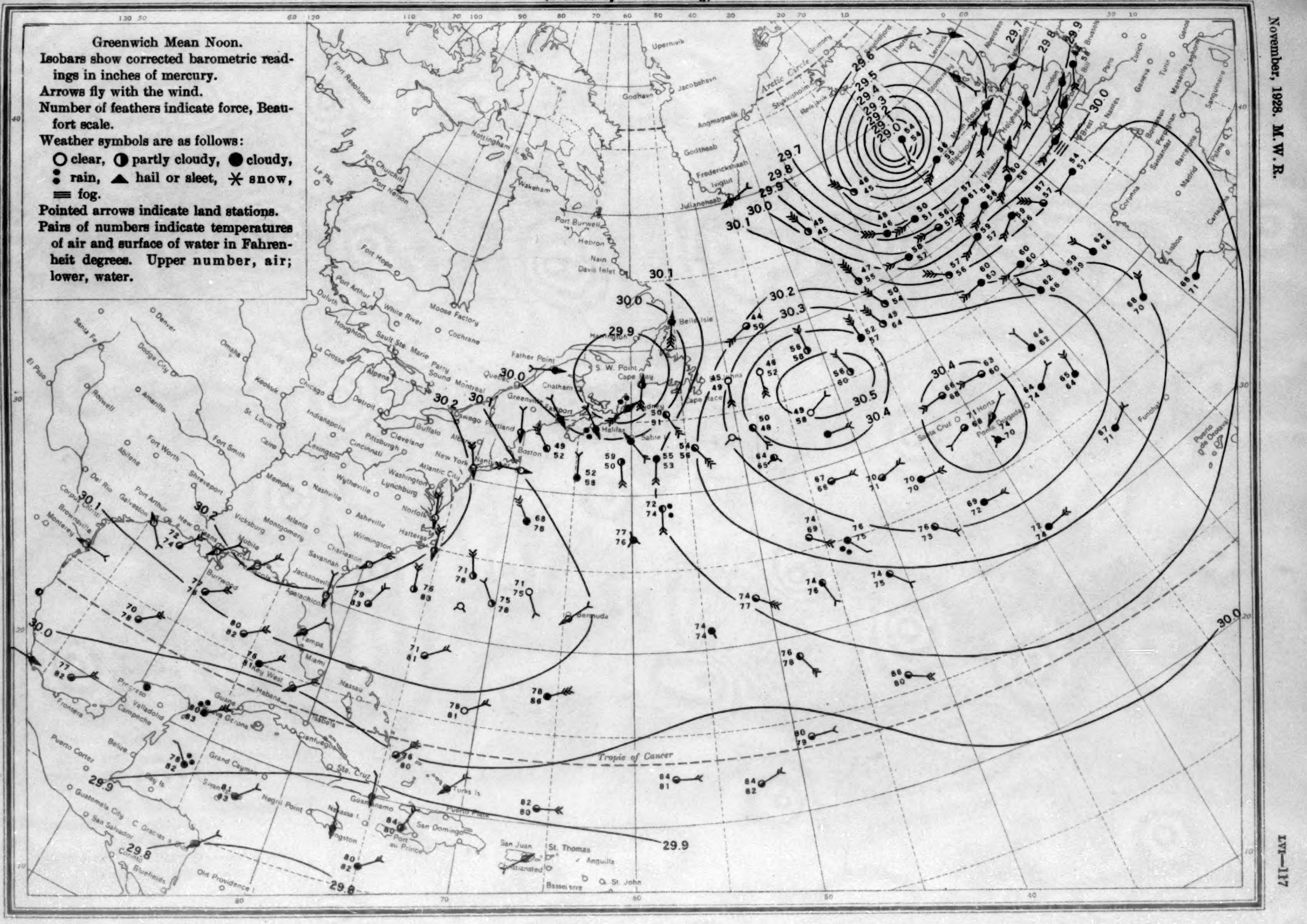


Chart IX. Weather Map of North Atlantic Ocean, October 30, 1928
(Plotted by F. A. Young)

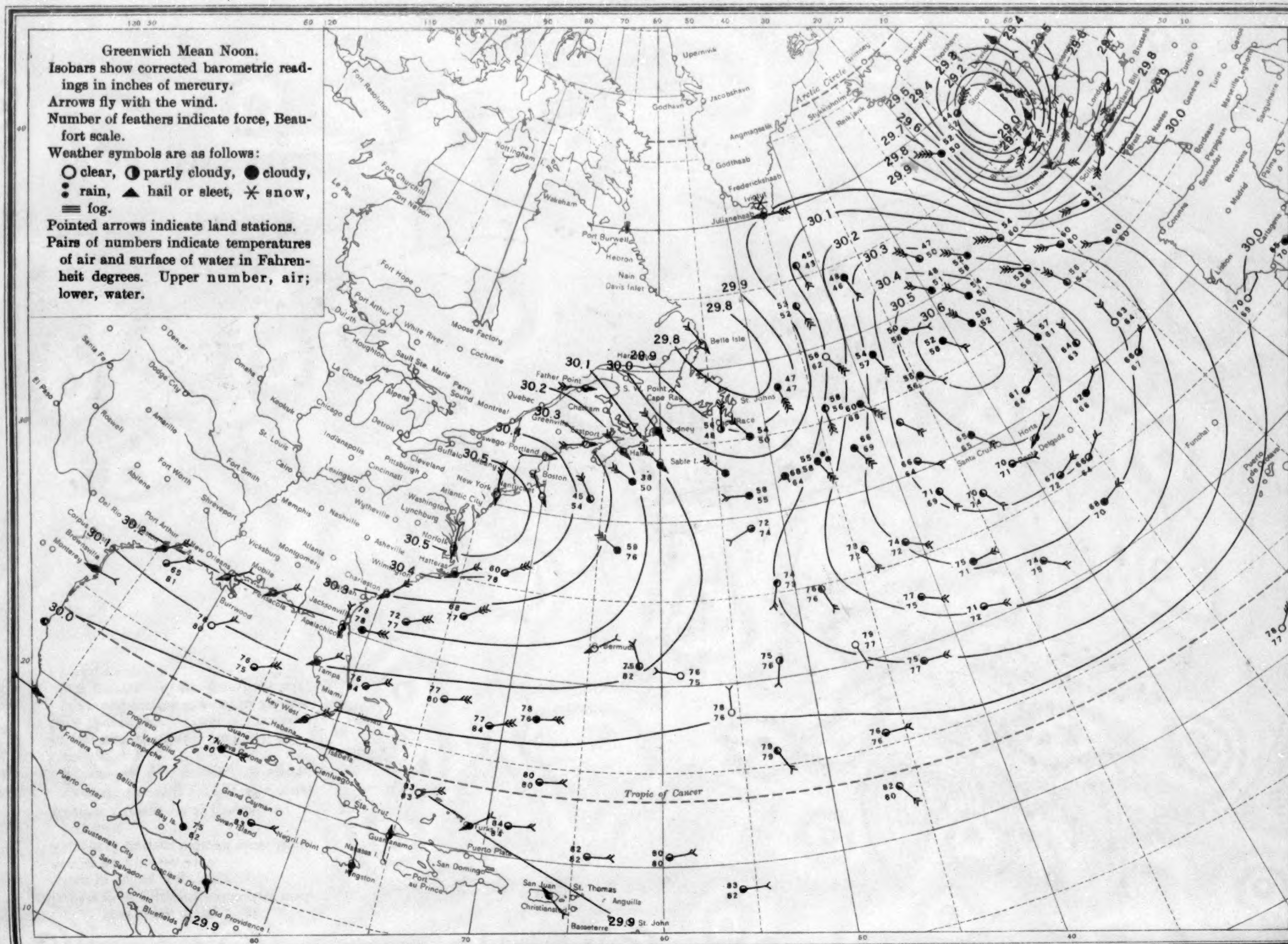
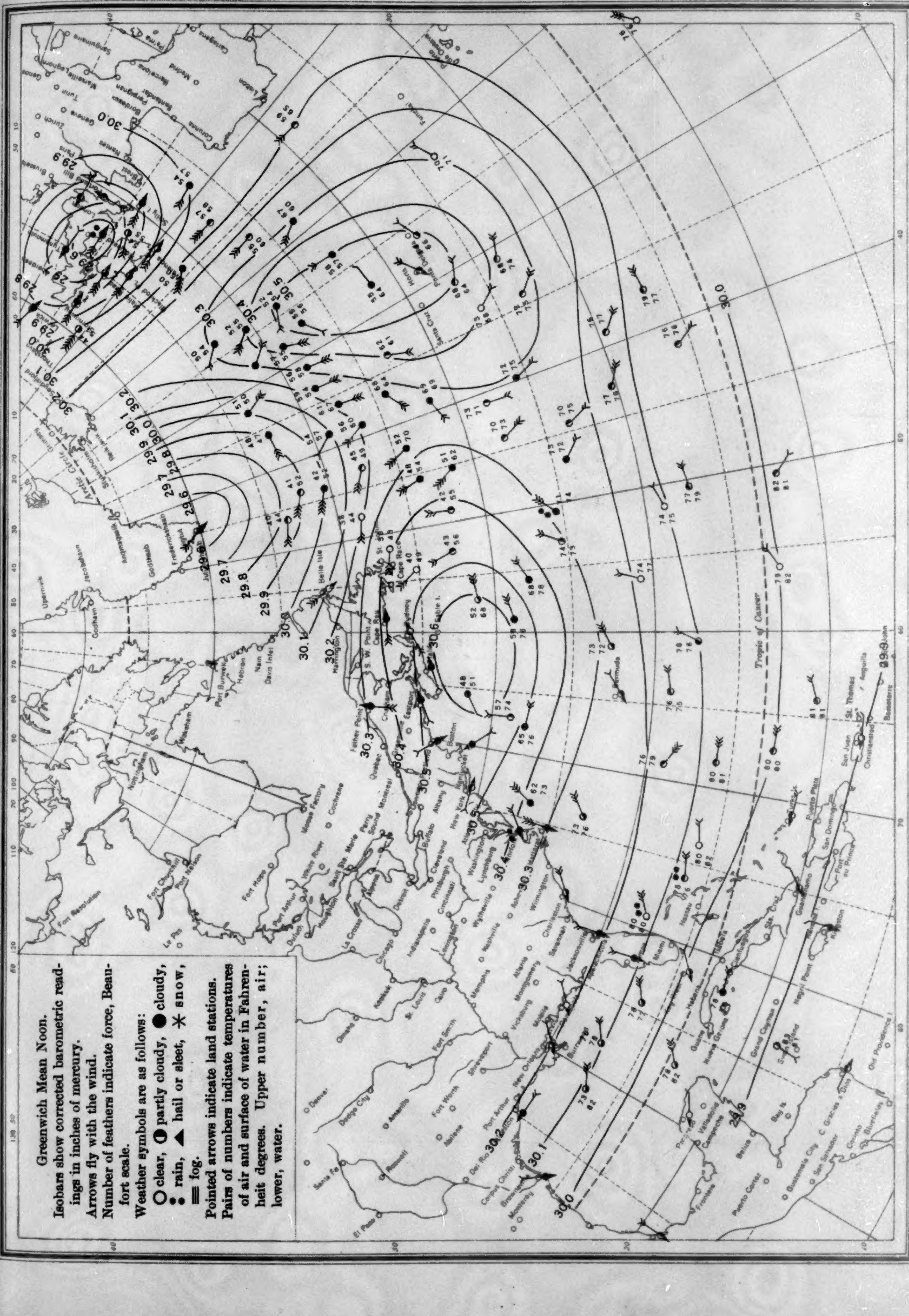


Chart X. Weather Map of North Atlantic Ocean, October 31, 1928
(Plotted by F. A. Young)



Greenwich Mean Noon.
Isobars show corrected barometric readings in inches of mercury.
Arrows fly with the wind.
Number of feathers indicate force, Beaufort scale.
Weather symbols are as follows: ○ clear, ◐ partly cloudy, ● cloudy, ⁏ rain, ▲ hail or sleet, ✱ snow, ≡ fog.
Pointed arrows indicate land stations.
Pairs of numbers indicate temperatures of air and surface of water in Fahrenheit degrees. Upper number, air; lower, water.

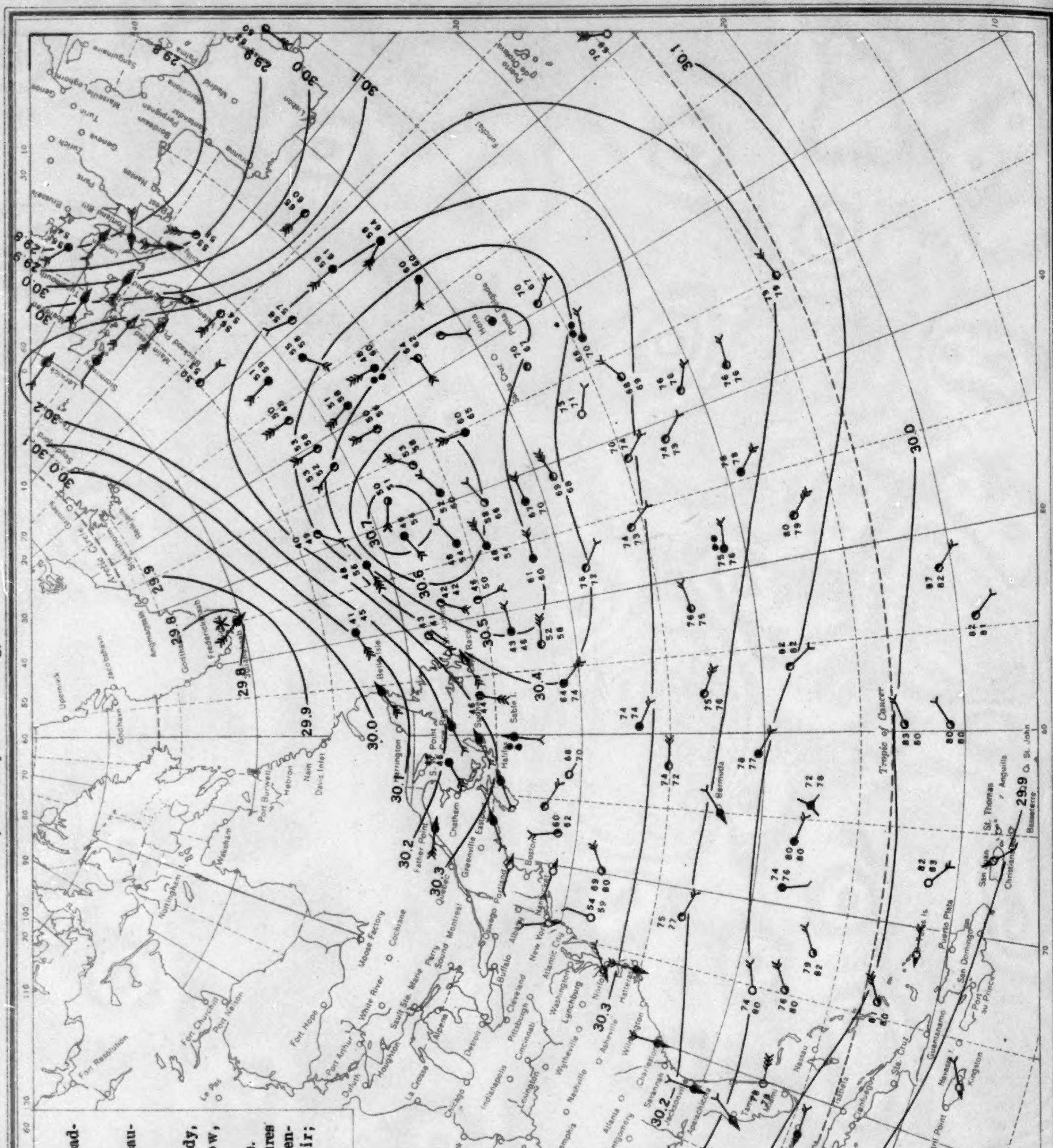


Chart XI. Weather Map of North Atlantic Ocean, November 1, 1928
(Plotted by F. A. Young)